# BMSD 2015

Fifth International Symposium on

# Business Modeling and Software Design

# Proceedings

Milan, Italy • 6-8 July 2015

Organized by: IICREST

Co-Organized by: Politecnico di Milano

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Cooperating Organizations: Aristotle University of Thessaloniki, BAS - Institute of Mathematics and Informatics, CTIT Centre for Telematics and Information Technology, SIKS, AMAKOTA

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**AUTH - Aristotle University of Thessaloniki**
**CTIT - the Center for Telematics and Information Technology of University of Twente**
**IMI - the Institute of Mathematics and Informatics of Bulgarian Academy of Sciences**
**SIKS - the Dutch Research School for Information and Knowledge Systems**
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Politecnico di Milano

Italy

**Marijn Janssen**

Delft University of Technology

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# BEST PAPERS SELECTION

The authors of around ten selected papers presented at BMSD 2015 will be invited by Springer-Verlag to submit revised and extended versions of their papers for publication in a Springer LNBIP Series book

# FOREWORD

Using business / enterprise models as a basis for software generation is receiving much attention and that particular role of business models is three-fold: (a) reaching an adequate integration of the software system in its enterprise (real-life) context; (b) achieving an enterprise-software traceability; (c) possibly identifying re-usable business modeling constructs and relating them to corresponding software components. Hence, we argue that an information system can only be adequate if properly restricted by a business model, since this justifies the link to the real-life context. A business model in turn is not only about the business processes and their management but also about the ways value is created, delivered, and captured. That all brings together technical disciplines (such as informatics), economic disciplines (such as management), and social disciplines (such as psychology) – those are brought together in the challenge of adequately delivering (complex) technology-enabled services to real-life customers.

Thus, developing ADAPTABLE INFORMATION SYSTEMS is considered important because of the constantly changing real-life environment to which (as explained above) the information system should conform. "Towards Adaptable Information Systems" is the theme of BMSD 2015 – the *Fifth International Symposium on Business Modeling and Software Design*, and the scientific areas of interest to the symposium are: (a) business models and requirements; (b) business models and services; (c) business models and software; (d) information systems architectures. Further, there are two application-oriented special sessions, namely: a special session on IT Solutions for Healthcare and a special session on Intelligent Applications of InterCriteria Decision Making Analysis. Those special sessions are bringing additional practice-driven value to the symposium.

In considering the above-mentioned areas, it is important to stress the interdisciplinary drive of BMSD - *business modeling* and *software design*. We consider business models from the perspective of their restricting software specification and we consider software design as (ideally) stemming from underlying business models. Business models are not only about reflecting entities, processes, and rules at enterprise level but also about capturing human feelings, beliefs, intentions, and commitments. As for software specifications, they are based on algorithms and measurable inputs, and assume technical complexity. Hence, reflecting business models in software specifications is not trivial: (i) a number of real-life human issues are to restrict the software (otherwise it would not fit its real-life context); (ii) at the same time, in developing software, one would inevitably get technically restricted by the platforms and technologies chosen to be used. How to balance between (i) and (ii) has been widely researched during the past 15 years but we still miss a definitive and widely accepted approach on that. Model-driven engineering (through its MDA "realization") is not a solution because it assumes as "starting point" a computation-independent model of the software system-to-be but real-life human aspects (as discussed above) are not captured. Service-oriented computing is not giving the answer too even though it "justifies" the challenge on balancing between (i) and (ii), by letting users compose services at high level (not being aware of the underlying technical complexity) while the services themselves are being realized by implemented software components - it is obviously impossible to guarantee that all the user demands (as real-life effect from using the service(s)) would be exhaustively delivered by a service(s) whose underlying software components have already been implemented with no idea of these particular user demands. The "best" we can see is that IT systems and services appear to be "thinking" of what the user should need and offering RESTRICTED solutions to which the user is "forced" to adapt. But that is NOT a provisioning of adaptable information systems. On the contrary - it a provisioning of information systems asking the user to adapt. Those are only some discussion points relevant to the enterprise engineering area and its relation to information systems development, being dominant for the researchers and practitioners that BMSD brings together, demonstrating for a fifth consecutive year a high quality of papers and presentations as well as a stimulating discussion environment.

This book contains the proceedings of BMSD 2015, held in Milan, Italy, on 6-8 July 2015. The proceedings consists of 36 high-quality research and experience papers that have not been published previously. Those papers have undergone a detailed peer-review process and were selected based on rigorous quality standards.

BMSD 2015 was organized and sponsored by the *Interdisciplinary Institute for Collaboration and Research on Enterprise Systems and Technology* (IICREST), being co-organized by *Politecnico di Milano* and technically co-sponsored by *BPM-D*. Cooperating organizations were *Aristotle University of Thessaloniki* (AUTH), the UTwente *Center for Telematics and Information Technology* (CTIT), the BAS *Institute of Mathematics and Informatics* (IMI), the Dutch Research *School for Information and Knowledge Systems* (SIKS), and *AMAKOTA Ltd.*

Since 2011, we have enjoyed four successful BMSD editions, namely: *Sofia 2011*, *Geneva 2012*, *Noordwijkerhout 2013*, and *Luxembourg 2014*. The Milan 2015 edition is the fifth one and we are proud to have succeeded in establishing and maintaining high scientific quality and stimulating collaborative atmosphere. Our community is of high competence and also inspired to share ideas and experience. In addressing the above-mentioned challenges and in line with the BMSD areas, BMSD 2015 is addressing a large number of research topics: from more conceptual ones, such as business process management & change management, data capturing and analysis & context modeling, enterprise modeling & meta-modeling & model transformations & model variants, (domain-specific) modeling languages, value modeling, capability-affordance modeling, and scheduling algorithms & recommendation algorithms, to more technical ones, such as software specification, service cloud applications & service-level agreements, information security & security certification, semantic web technologies, technical debt, and discrete event simulation, from more business-oriented ones, such as business model design, business modeling ontologies, requirements specification, and business-IT alignment + business strategies for emerging technologies, to topics related to (distributed) software systems and architectures. We are impressed by those research contributions touching upon challenging (technical) problems and also presenting solutions and ideas of high innovative potential.

BMSD 2015 received 57 paper submissions from which 36 papers were selected (including several invited papers) for publication in the current proceedings. 14 of those papers were selected for a

30-minute oral presentation (full papers), leading to a *full-paper acceptance ratio of 24%* (compared to 23% in 2014). In addition: 20 papers were selected for a 20-minute oral presentation (short papers and special sessions papers); 2 papers were selected for a poster presentation. The above-mentioned full-paper acceptance ratio shows a high BMSD quality which we intend to maintain and reinforce in the following editions of the symposium. Further, the BMSD'15 authors are from: Austria, Belgium, Bulgaria, Greece, Egypt, Finland, Germany, India, Italy, Japan, Kazakhstan, The Netherlands, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Tunisia, UK, and USA (listed alphabetically); that makes a total of 21 countries (compared to 21 in 2014, 14 in 2013, 11 in 2012, and 10 in 2011) to justify a strong international presence. Finally, 6 countries have been represented at all 5 BMSD editions so far – those are: *Belgium*, *Bulgaria*, *Germany*, *The Netherlands*, *Switzerland*, and *UK*, to indicate a strong European influence.

Publisher of the current proceedings is *SCITEPRESS*. Besides printed proceedings we also deliver an electronic version – all presented papers will be made available on the *SCITEPRESS Digital Library* by September, 2015. Furthermore, the proceedings will be submitted to *DBLP* (Computer Science Bibliography) for indexation. Finally, the authors of around ten selected papers presented at BMSD 2015 will be invited by *Springer-Verlag* to submit revised and extended versions of their papers for publication in a Springer LNBIP (Lecture Notes in Business Information Processing) Series book.

The high quality of the BMSD 2015 program is enhanced by two keynote lectures, delivered by distinguished guests who are renowned experts in their fields: *Barbara Pernici* (Politecnico di Milano) and *Marijn Janssen* (Delft University of Technology). The keynote speakers and some other BMSD'15 participants will take part in a panel discussion and also in other discussions stimulating community building and facilitating possible R&D project acquisition initiatives. Those special activities will definitely contribute to maintaining the event's high quality and inspiring our steady and motivated community.

Organizing this interesting and successful symposium required the dedicated efforts of many people. Firstly, we must thank the authors, whose research and development achievements are recorded here. Next, the program committee members each deserve credit for the diligent and rigorous peer-reviewing. Further, we would like to mention the excellent organization provided by the IICREST team (supported by its logistics partner, AMAKOTA Ltd.) – the team did all the necessary work for delivering a stimulating and productive event, and we have to acknowledge also the support of *Dimitris Mitrakos* and *Diana Vesselinova*. We appreciate the cooperation of our colleagues from Politecnico di Milano. We are grateful to SCITEPRESS for their willingness to publish the current proceedings and we bring forward special compliments to *Vitor Pedrosa* for his professional work and brilliant collaboration with regard to the proceedings preparation. Last but not least, we thank the keynote speakers for their invaluable contribution and for taking the time to synthesize and deliver their talks.

We wish you all an inspiring symposium and an enjoyable stay in the beautiful city of Milan. We look forward to seeing you next year in Rhodes, Greece, for the Sixth International Symposium on Business Modeling and Software Design (BMSD 2016), details of which will be made available on *http://www.is-bmsd.org.*

I dedicate my work on leading BMSD 2015 to the memory of my father, *Blagovest.*

**Boris Shishkov**
Bulgarian Academy of Sciences / IICREST, Bulgaria

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## SPECIAL SESSION ON INTELLIGENT APPLICATIONS OF INTERCRITERIA DECISION MAKING ANALYSIS

# KEYNOTE SPEAKERS

# Processes and Data

Barbara Pernici
*Politecnico di Milano, Italy*
*barbara.pernici@polimi.it*

Abstract: While in traditional business applications data management was confined to handling data necessary for performing the activities in processes according to a predefined process schema, and therefore process models focused on modeling the possible sequences of activities, the increasing volumes of data available nowadays are giving a different role to data also in processes. The talk will explore data modeling in processes, the implications of data quality and the management of data errors. Different types of processes will be discussed, focusing in particular on data flows and monitored data during process execution. Process monitoring provides a large quantity of data for process analysis, and the talk will discuss not only process redesign, but also the identification of critical events during process execution based on monitored data and strategies for taking adaptive corrective actions during the process execution.

## BRIEF BIOGRAPHY

Barbara Pernici is full professor in Computer Engineering at the Politecnico di Milano. Her research interests include adaptive information systems, service oriented computing, data quality, and energy efficiency in information systems. She has lead the POLIMI team in the European FP7 ECO2Clouds (Experimental Awareness of CO2 in Federated Cloud Sourcing) project and scientific leader in the FP7 European project GAMES (Green Active Management of Energy in Service Centers). She is member of the Management Committee of the COST 1304 Action ACROSS (Autonomous Control for a Reliable Internet of Services). She has been elected chair of TC8 Information Systems of the International Federation for Information Processing (IFIP), of IFIP WG 8.1 on Information Systems Design, and vice-chair of the IFIP WG on Services-Oriented Software. She is Head of the PhD School of Politecnico di Milano since 2011.

# Architectural Governance and Organizational Performance

Marijn Janssen
*Delft University of Technology, The Netherlands*
*M.F.W.H.A.Janssen@tudelft.nl*

Abstract: Based on a study of more than 15 cases analyses show that architectural governance is a condition for success. Architectural governance introduces more bureaucracy and administrative work, but paradoxically can result in more flexibility and agility. Architectural governance complements architecture and often architecture and architectural governance are strongly connected, making it difficult to separate them. This strong dependence requests that a change in architecture influences the governance and vice versa.

## BRIEF BIOGRAPHY

Dr. Marijn Janssen is full Professor in ICT & Governance and head of the Information and Communication Technology section of the Technology, Policy and Management Faculty of Delft University of Technology. His research interests are in the field of orchestration, (shared) services, intermediaries, open data and infrastructures within constellations of public and private organizations. He serves on several editorial boards and is involved in the organization of a number of conferences. He published over 300 refereed publications. More information: www.tbm.tudelft.nl/marijnj.

# FULL PAPERS

# Adapting Processes via Adaptation Processes:
## *A Flexible and Cloud-Capable Adaptation Approach for Dynamic Business Process Management*

Roy Oberhauser
*Computer Science Department, Aalen University, Aalen, Germany*
*roy.oberhauser@htw-aalen.de*

Keywords: Dynamic Business Process Management, Dynamic BPM, Adaptive Process-Aware Information Systems, PAIS, Adaptive Workflow Management Systems, Process Change Patterns, Aspect-Oriented Processes, Cloud-based BPM, Adaptation-as-a-Service, Web Services.

Abstract: Dynamic business process management (dBPM) is dependent on automated adaptation techniques. While various approaches to support process adaptation have been explored, they typically involve another or some combination of modeling paradigms or language extensions. Moreover, cross-cutting concerns and a distributed and cloud-based process adaptation capability have not been adequately addressed. This paper introduces AProPro (Adapting Processes via Processes), a flexible and cloud-capable approach towards dBPM that supports adapting target processes using adaptation processes while retaining an intuitive and consistent imperative process paradigm. Based on a case study using a REST-based Web Service prototype realization invoking process adaptation patterns in a distributed of Adaptation-as-a-Service cloud setting, the initial evaluation results show the feasibility of the approach and gauge its performance in the cloud.

## 1 INTRODUCTION

Dynamic business process management (dBPM) seeks to support the reactive or evolutionary modification or transformation of business processes based on environmental conditions or changes. The technical realization of business processes, known as executable processes or workflows, are implemented in what is known as either a business process management system (BPMS), workflow management system (WfMS), or process-aware information system (PAIS).

However, many PAISs today lack dynamic runtime adaptation with correctness and soundness guarantees (Reichert et al., 2009). And when such adaptation is supported, it is typically limited to support for manual change interaction by a process actor (Reichert & Weber, 2012). Typical types of recurring modifications to workflows are known as workflow control-flow patterns (Russell, van der Aalst & ter Hofstede, 2006), change patterns (Weber, Reichert & Rinderle-Ma, 2008) or adaptation patterns (Reichert & Weber, 2012).

In light of the dBPM vision, as the degree of automation and workflow usage increases, there is a corresponding need to support adaptation by agents, be they human or software. Our previous work on an adaptable context-aware and semantically-enhanced PAIS in the software engineering domain (Grambow, Oberhauser & Reichert, 2010, 2011a, 2011b) included automated adaptation work and work on supporting the user-centric intentional adaptation of workflows (Grambow et al., 2012). However, an open challenge remains towards practically expressing and maintaining adaptations in an intuitive manner for process modelers and process actors for a sustainable dBPM lifecycle.

This paper introduces and contributes a practical and flexible cloud-capable approach called Adapting Processes via adaptation Processes (AProPro) for supporting dBPM in a generalized way that can be readily implemented and integrated with current adaptive PAIS technology. It supports the ease and accessibility of process adaptations in an intuitive imperative PAIS paradigm for process modelers and process actors or users. It can further the maintenance, reuse, portability, and sharing of adaptations, including cloud-based provisioning of adaptation processes within the community, thus supporting sustainable adaptability by extending an adaptation process's lifecycle. A case-study demonstrates its feasibility and its cloud-based performance.

The paper is organized as follows: section 2 describes related work, followed by a description of the solution approach. A technical realization is described in section 4, followed by an evaluation. Section 6 concludes the paper. Larger figures are placed in the appendix. Since this paper focuses on the technical implementation of a process, the terms workflow and process are used interchangeably.

# 2 RELATED WORK

Various approaches exist that can support the manual or automated adaption of workflows. The survey by (Rinderle, Reichert & Dadam, 2004) provides an overview from the perspective of support for correctness criteria. (Weber, Reichert & Rinderle-Ma, 2008) provide an overview based on the perspective of change patterns and support features.

*Declarative approaches*, such as DECLARE (Pesic, Schonenberg & van der Aalst, 2007) support the constraint-based composition, execution, and adaptation of workflows. *Case handling approaches*, such as FLOWer (Van der Aalst, Weske & Grünbauer, 2005), typically attempt to anticipate change. They utilize a case metaphor rather than require process changes, deemphasize activities, and are data-driven (Reichert & Weber, 2012) (Weske, 2012). (de Man, 2009) provides a review of case modeling approaches. Case-based approaches towards adapting workflows include (Minor, Bergmann, Görg & Walter, 2010). *Agent-based approaches* support automated process adaptations applied by autonomous software agents. Agentwork (Müller, Greiner & Rahm, 2004) applies predefined change operations to process instances using rules. (Burmeister, Arnold, Copaciu & Rimassa, 2008) applies a belief-desire-intention (BDI) agent using a goal-oriented BPMN modeling language extension. *Aspect-oriented approaches* include AO4BPEL (Charfi & Mezini, 2007) and AO4BPMN (Charfi, Müller & Mezini, 2010), both of which require language extensions. *Variant approaches* include: Provop (Hallerbach, Bauer & Reichert, 2010), which supports schema variants with pre-configured adaptations to a base process schema; and vBPMN (Döhring & Zimmermann, 2011) that extends BPMN with fragment-based adaptations via the R2ML rule language. rBPMN (Milanovic, Gasevic & Rocha, 2011) also interweaves BPMN and R2ML. *Automated planning* and *exception-driven adaptation approaches* include SmartPM (Marrella, Mecella & Sardina, 2014), which utilizes artificial intelligence, procedural, and declarative elements.

AProPro differs in that it is an imperative workflow-based adaptation approach that does not require a case metaphor and is activity-, service-, and process-centric with regard to runtime adaptation. Additionally, no language extensions or other paradigms such as rules, declarative elements, or intelligent agents are required. Further, distributed and cloud-based adaptations to either instances or schemas are supported.

# 3 SOLUTION APPROACH

The AProPro approach follows an imperative style, and process models are kept as simple and modular as reasonable for typical usage scenarios. This is in alignment with the orthogonal modularity pattern (La Rosa, Wohed, et al., 2011). Special cases can either be separated out or handled as adaptations via adaptation processes. A guiding principle of the AProPro approach is that adaptations to processes should themselves be modeled as processes, remaining consistent with the process paradigm and mindset. The solution scope focuses primarily on adapting process control structures, and not necessarily all adaptations to processes can be accomplished with this approach. In particular, internal activity changes, non-control and (internal) data structure changes, and implicit dependencies are beyond the scope of this paper.

The following description of the solution approach will highlight certain perspectives. As shown in Figure 1, *Process Instances (PI1..n)* are typically instantiated *(1)* based on some *Process Schema (S)* within a given PAIS (filled with diagonal hatching). In adaptive PAISs, *Adaptation Agents (AA)* (shown on the left with a solid fill), be they human or software agents, utilizing or reacting to *Information (I)* (e.g., external information such as context or other internal system information such as planning heuristics) or *Monitoring Information (MI)*, trigger modifications to various process structures. A *Schema Adaptation Agent (SAA)*, such as a process designer or modeler, makes *Schema Adaptions (SA)* to one or more *Process Schema (PS)*. An *Instance Adaptation Agent (IAA)*, such as a process actor or user, may perform *Adaptations (A)* on some *Process Instance (PI)*. Support for such adaptation has been available in adaptive PAISs, e.g., the ADEPT2-based AristaFlow (Reichert & Weber, 2012, Ch. 15).

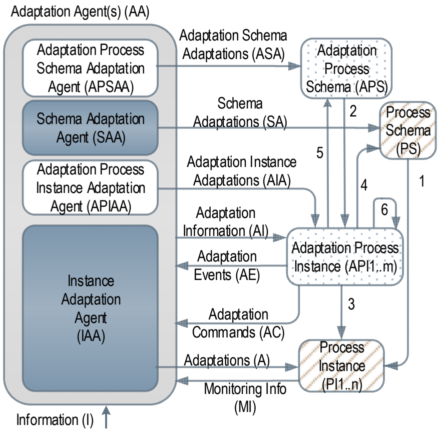


Figure 1: Conceptual solution architecture.

<u>Workflow-driven adaptations of workflows</u>: adaptations, such as adaptation patterns, are specified in the form of workflows that will operate on another workflow. For this (see Figure 1 dotted fill), an *Adaptation Process Schema (AS)* is created or modified from which one or more *Adaptation Process Instances (API1..m)* are instantiated *(2)* in the same or a different PAIS. The *(API)* to target *(PI)* relation may be one-to-one, one-to-many, many-to-one, or many-to-many. Utilizing *Adaptation Information (AI)* such as events, triggers, or state, automated instructions denoted as *Adaptation Commands (AC)* can be sent to an *Instance Adaptation Agent (IAA)* that executes *Adaptations (A)* on one or more *(PI)*. Note that in certain PAIS architectures, a direct adaptation mechanism *(3)* that avoids the *(IAA)* intermediary may exist, with *(API)* acting as an *(IAA)*. *(API)* may provide *Adaptation Events (AE)*, e.g., so that an *(AA)* can be aware of the current state of an *(API)*.

<u>Adaptation patterns as workflows</u>: Adaptation patterns (insert, delete, move, replace, swap, inline, extract, parallelize, etc.) can be integrated in workflows and applied conditionally based on *Adaptation Information (AI)*, e.g., in the form of process variables or events.

<u>Aspect-oriented adaptations</u>: this is supported by modularizing and constraining an adaptive workflow to operate on one aspect (such as authorization), while having other adaptation workflows address others. The many-to-many relations between *(API)* and *(PI)* or *Schemas (PS)* was previously mentioned. Congruent with the chain-of-responsibility design pattern, adaptations can be modularized and chained.

<u>Variation points</u>: these can be intentionally incorporated via markers for explicit adaptation support during process modeling, e.g., given insufficient modeling information. Adaptation workflows can then dynamically "fill in" these areas during process configuration or enactment.

<u>Adapting adaptation workflows</u>: This concept supports a further degree of flexibility by supporting adaptation workflows operating on (other) adaptation workflows. *Adaptation Process Instances (API)* send *Adaptation Commands (AC)* resulting in *Schema Adaptations (SA)* to a *Process Schema (PS)*, either via a *Schema Adaptation Agent (SAA)* or directly via *(4)*. In a similar fashion, *Adaptation Schema Adaptations (ASA)* can be applied to an *Adaptation Process Schema (APS)* via an *Adaptation Process Schema Adaptation Agent (APSAA)* or directly via *(5)*. Note that in this case, an *(API)* can change its own schema *(APS)* or those of others, and potentially change itself *(API)* or other instances *(API)*, possibly even directly via *(6)*.

<u>Recursive adaptation</u>: instead of separating the *(API)* from its target *(PI)*, if preferable (for instance, to access contextual data), a *(PI)* can include its own *(APS)* fragments and thus become self-modifying.

<u>Exception-based adaptations</u>: (un)anticipated exceptions can be used to trigger the enactment of adaptation workflows within exception handlers.

<u>Reactive and proactive adaptations</u>: in support of dBPM, event- and context-driven changes can automatically trigger and cause automated predictive or reactive runtime adaptations to be incorporated on an as-needed basis, rather than taking all possibilities into process models a priori.

<u>Push-or-pull adaptations</u>: for push, the adaptive workflow is triggered first and applies its changes to the target; for pull, the target workflow triggers the adaptive workflow to initiate its adaptations.

<u>Reusability</u>: shared modeled/tested adaptation workflows support the wider reuse of adaptation patterns in the community, e.g., via repositories like APROMORE (La Rosa, Reijers, et al., 2011).

<u>Composability</u>: more complex adaptations can be addressed by composing multiple adaptation workflows, e.g., via sub-processes into larger ones.

<u>Process Compliance and Governance</u>: the (AP) can be used to verify expected structural and state conditions (no changes applied), or to additionally apply adaptations when these are not in compliance.

<u>Cloud-based provisioning of adaptation workflows</u>: the concept supports operating in a distributed and PAIS-independent (heterogeneous) manner on other workflows in other clouds, making these adaptation workflows readily available to operate on others as needed. Shared tenancy and pay for use could reduce infrastructural costs.

<u>Service-oriented adaptation services</u>: the approach supports the ability to provision and support adaptations-as-a-service (AaaS) in the cloud.

Thus, AProPro supports the goals of dBPM by enabling desired automated or semi-automated adaptations, while allowing process modelers and users to remain in their current process paradigm and modeling language without requiring language extensions. Empirical findings that support such an approach includes: (Haisjackl et al., 2014) who empirically investigated understandability issues with declarative modeling, and found that subjects tended to model sequentially and had difficulty with combinations of constraints; (Pichler et al., 2012) determined that imperative models have better understandability and comprehensibility than declarative ones; (Reijers, Mendling, & Dijkman, 2011) suggests that process modularity via information hiding enhances understandability; and (Döhring, Reijers & Smirnov, 2014), which showed that process complexity affected maintenance task efficiency for process variant construction - here subjects preferred high-level change patterns to process configuration.

# 4 REALIZATION

To verify the feasibility of the AProPro approach, key aspects of the solution concept were implemented utilizing the adaptive PAIS AristaFlow. The solution approach required no internal changes to this PAIS, relying exclusively on its available extension mechanisms via its generic Java method execution environment. RESTful web services were used for cloud interaction. Adaptation workflow activity nodes utilize a `StaticJavaCall` to invoke the extension code contained in a Java ARchive (JAR) file, which sends change requests to a REST server in the same or another PAIS.

To support heterogeneity, both the communication and the change requests are PAIS agnostic. They could thus be invoked and sent by any PAIS activity in any adaptation workflow located anywhere. Only the actual workflow change operations require a PAIS-specific API. Other PAIS implementations can be relatively easily integrated via plug-in adapters.

## 4.1 Adaptation Patterns and AaaS

The initial realization focused on demonstrating key AProPro and AaaS capabilities basic to typical adaptations: inserting, deleting, and moving process fragments. On this basis, more complex adaptation workflows can be readily built. For instance, the replace change pattern was realized as a subprocess consisting of an insert and a delete operation.

The AristaFlow application programming interface (API) expects various method input parameters in order to modify a workflow. Thus, pattern implementations were designed to include these expected values even if some are optional.

The *insert process fragment pattern*, shown in Figure 2(a), takes the following input parameters:

- *procID*: ID of the target process instance;
- *pre*: ID of the predecessor node;
- *suc*: ID of the successor node;
- *activityID*: ID of activity assigned to node;
- *newNodeName*: name of the new node;
- *staffAssignmentRule*: of this node;
- *description*: of this node;
- *readParameter*: input parameters for the new node;
- *writeParameter*: output parameters of the new node.

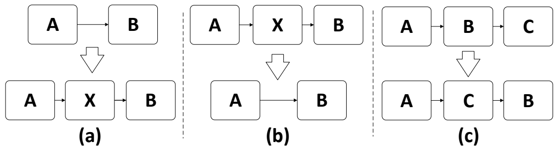


Figure 2: (a) insert, (b) delete, and (c) move process fragment patterns.

The *delete process fragment pattern*, shown in Figure 2(b), takes the following input parameters:

- *procID*: ID of the target process instance;
- *nodeID*: ID of the node to be deleted.

The *move process fragment pattern*, shown in Figure 2(c), takes the following input parameters:

- *procID*: ID of the target process instance;
- *pre*: ID of the new predecessor node;
- *suc*: ID of the new successor node;
- *nodeID*: ID of the node to be moved.

The *replace* pattern was realized as a subprocess that uses the insert and delete patterns (see Figure 6).

RESTful web services were created in Java according to JAX-RS using Apache CXF 2.7.7, with Java clients using Unirest 1.4.5. For basic pattern AaaS services, the following corresponding REST operations were provided at the target PAIS containing the target workflows to be modified, with procID passed in the URI and the rest of the inputs described above passed as parameters:

- `PUT /procID/{procID}/insert`
- `PUT /procID/{procID}/delete`
- `PUT /procID/{procID}/move`

The following REST operations provide the interface for more advanced AaaS services that invoke adaptation workflows which modify a separate target workflow instance. These processes are explained later in the evaluation section, the technical interface parameters of the adaptation service implementations are given here:

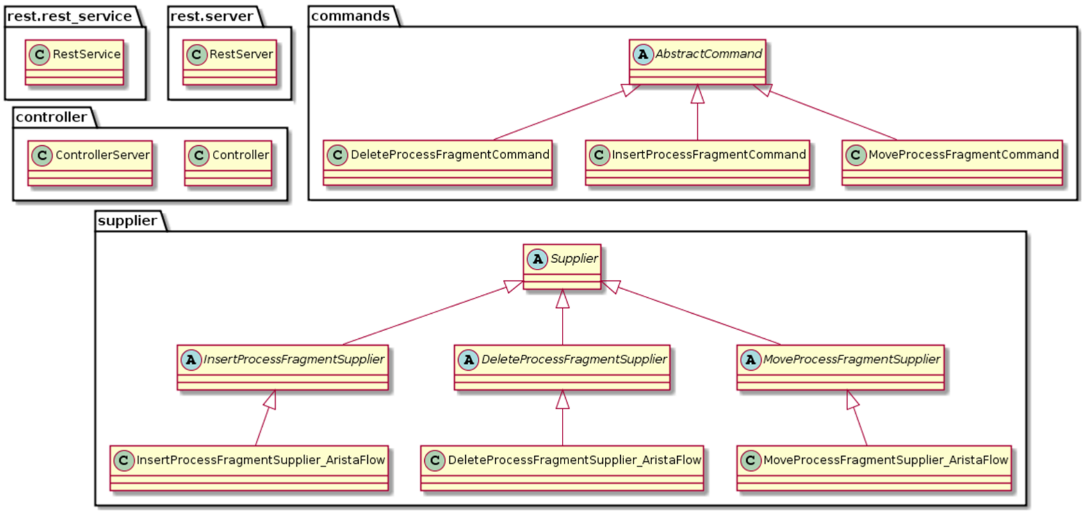


Figure 3: UML2 class diagram showing key implementation packages and classes.

- For quality assurance: `PUT /procID/{procID}/adapt/qa` with the string parameters urgent, high risk, junior engineer, and targetIP;
- For test-driven development: `PUT /procID/{procID}/adapt/tdd` with the string parameters testDriven and targetIP.

## 4.2 Implementation Details

The AaaS client-side adaptation process nodes internally invoke static methods in the `ChangeOperations` class for that change pattern (`doInsertProcessFragment` or equivalent). This method invokes a REST client that sends the corresponding request to a REST server. The service determines the type of *Request*, on which basis a corresponding (e.g., *InsertProcessFragment*-) *Command* object is instantiated and passed to a *Controller*, which determines when and in what sequence to execute a given command. Refer to Figure 3. To support heterogeneity, the commands utilize the corresponding *Supplier* classes which utilize PAIS-specific APIs for the operations.

A lock is acquired for the AristaFlow target process instance and a *ChangeableInstance* object is generated. All changes are first applied to this *ChangeableInstance* object. When the changes are committed, the entire instance is checked by AristaFlow for correctness. If the changes are correct, the actual process instance is modified accordingly. If errors were found, the changes are rejected and the actual process instance remains unchanged.

# 5 EVALUATION

To evaluate the solution concept and one realization thereof, this initial case study focused on demonstrating key process adaptation capabilities of the concept and assessing its viability with respect to performance, especially for a distributed cloud scenario. The solution concept envisions provisioned adaptation workflows in the cloud that are available to operate on other workflows. Since certain reactive dBPM scenarios may be sensitive to delays, the technical evaluation encompassed cloud performance measurements. Workflows operating across geographically separate PAISs utilizing a basic cloud configuration would represent a worst case area of the performance spectrum.

Figure 4 shows the evaluation setup. System A, which ran the adaptation workflows, was an Amazon AWS EC2 t2.micro instance eu-central-1b in Frankfurt, Germany consisting of an Intel Xeon E5-2670 v2@2.50GHz, 1 GB RAM, 1 Gbps network, AristaFlow PAIS 1.0.92 - r19, Windows 2012 R2 Standard x64, and Java 1.8.0_45-b15. System B was an equivalent Amazon AWS EC2 t2.micro instance on the US West Coast (Northern California) us-west-1b containing the target workflows. A remote configuration means A is active and communicates with its target on B. A local configuration implies that the Adaptation Process is collocated with the Target Process within the same PAIS, but commands are still sent via REST.

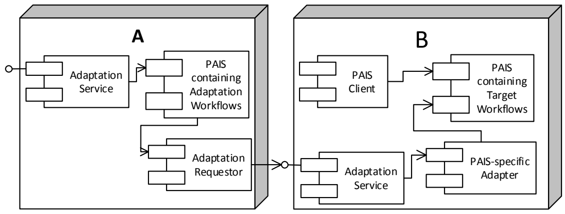


Figure 4: AWS cloud evaluation setup.

The test procedure was as follows: On system B the Apache CXF REST server was started, and then the target workflow was manually started via the AristaFlow client to bring it into a started initialized state. On system A an adaptation workflow was triggered by a REST client using Postman 2.0 in a Chrome web browser with which the necessary adaptation parameters were entered (e.g., procID, target workflow IP address, etc.). Activities in the adaptation workflow send adaptation requests via REST to system B. All latency and processing times were measured within systems A and B.

## 5.1 Case Study

While the solution concept is domain independent, this case study uses software engineering (SE) processes to illustrate the capabilities and adaptation effects. The branches and loops involved in realistic models are omitted for simplification and space.

### 5.1.1 Sequential Waterfall Process

For a representative target for the application of adaptation processes, a sequential workflow was chosen, loosely following a waterfall process (WP) consisting of common SE activities for an approved software change request. It represents any standard process in a fictitious organization. The activity sequence is shown in Figure 7.

### 5.1.2 Quality Assurance Adaptation Process

To demonstrate process governance and an Adaptation Process producing process variants, the Quality Assurance Adaptation Process (QAAP) variously adapts a target process based on situational factors.

Assume the SE process for a software change varies depending on its urgency, risk, and the worker's experience. The SE organization's policy normally expects at least a peer review before code is committed. The WP already includes this activity, although the adaptation workflow could also check policy compliance and insert such a missing activity.

Three configurable boolean parameters were utilized for this process in Figure 8: Urgent, High Risk, and Junior Engineer (denoting the worker experience level, with false implying a more senior worker). The 'SetConditions' task allows a user to set workflow values, which is skipped when invoked as a service. The following cases besides the default *Peer Review* (no change) were supported:

*Code Review Case*: A Code Review is required if the circumstances are 'NOT urgent AND (high risk OR junior engineer).' In this case:

- The node Peer Review is deleted via the Delete Process Fragment
- A node Code Review is inserted via the Insert Process Fragment Pattern

*No Review Case*: Foregoing a review is only tolerated when the situation is 'urgent AND NOT high risk AND NOT junior engineer.' In this case:

- The Peer Review node is removed via the Delete Process Fragment Pattern.

Figure 10 shows the result of the application of QAAP to WP for 'not urgent and high risk', resulting in activity Code Review replacing Peer Review. In a context-aware dBPM environment, such input values could also be automatically determined.

### 5.1.3 TDD Adaptation Process

In software test-driven development (TDD), test preparation activities precede corresponding development activities. To support the TDD aspect in the WP, Unit Test is placed before Implement and Integration Test before Integrate. Thus, the TDD Adaptation Process (TDDAP) shown in Figure 9 utilizes the Move Process Fragment Pattern twice. The resulting adaptations are shown in Figure 11.

### 5.1.4 Aspect-oriented Adaptations

Multiple separate Adaptation Processes can be advantageous for modularity and maintainability. Analogous to aspect-orientation, each aspect and its associated adaptations can be modeled in separate conditionally dependent Adaptation Processes. In Figure 12 both QAAP and TDDAP were applied to the target WP, with each Adaptation Process representing a different aspect (reviews or testing).

### 5.1.5 Self-adaptive Processes

Self-adaptive processes support the integrative modeling of possible adaptations into the target processes themselves. As shown in Figure 13, both the QAAP and TDDAP adaptations were modeled before the WP, with the target process for the adaptations being the enacting process instance itself. This demonstrates the feasibility of adapting adaptation workflows and of recursive adaptations, and in a similar way adaptations could be integrated into process exception handlers.

## 5.2 Measurements

To determine the performance of dBPM adaptation operations by an adaptation process in a geographically distributed cloud scenario, the durations for various basic operations (insert, delete, move) and adaptation processes (QAAP and TDDAP) were measured. In the case that an initial measurement was significantly longer than the ones following (e.g., due to initialization and caching effects), this value was noted separately and not included in the average, since a dormant adaptation process might exhibit such an effect, whereas an active adaptation process would not. Each measurement was repeated in accordance with setup and test procedure described previously. To gather upper bounds, no optimizations or performance tuning were attempted.

Table 1 through Table 3 show the results for the execution of the basic adaptation operations insert, delete, and move respectively in a local and a remote configuration. The average was calculated from the 4 repeated measurements that followed the initial measurement. To see if cloud network delays play a significant role, the network latencies and the adaptation times are differentiated, which is also depicted in Figure 5.

Table 1: Insert operation duration (in seconds).

| | Local (B to B) | | Remote (A to B) | |
|---|---|---|---|---|
| | Initial | Average | Initial | Average |
| Adaptation | 4.033 | 3.468 | 3.588 | 3.203 |
| Latency | 0.418 | 0.373 | 0.686 | 0.675 |
| Total | 4.451 | 3.842 | 4.275 | 3.878 |

Table 2: Delete operation duration (in seconds).

| | Local (B to B) | | Remote (A to B) | |
|---|---|---|---|---|
| | Initial | Average | Initial | Average |
| Adaptation | 3.251 | 3.295 | 2.880 | 3.749 |
| Latency | 0.444 | 0.448 | 1.013 | 0.674 |
| Total | 3.695 | 3.743 | 3.893 | 4.423 |

Table 3: Move operation duration (in seconds).

| | Local (B to B) | | Remote (A to B) | |
|---|---|---|---|---|
| | Initial | Average | Initial | Average |
| Adaptation | 6.796 | 3.311 | 6.105 | 4.005 |
| Latency | 0.577 | 0.347 | 0.772 | 0.692 |
| Total | 7.374 | 3.658 | 6.877 | 4.697 |

Table 4: Average Adaptation Process duration (seconds).

| | Local (B to B) | Remote (A to B) |
|---|---|---|
| QAAP (1 replace) | 15.748 | 16.285 |
| TDDAP (2 swaps) | 14.971 | 14.226 |

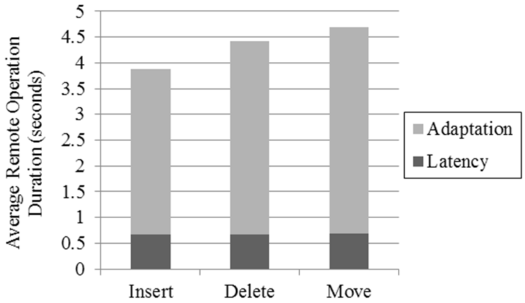


Figure 5: Average duration (in seconds) for various remote basic adaptation operations.

Table 4 shows average of 5 repeated execution durations for the QAAP and separately for the TDDAP.

For a self-adaptive process, Figure 13 combines the QAAP and TDDAP workflow fragments before the WP fragment. When executed 3 times in a local configuration, the average duration was 34.321 seconds. This corresponds closely with the sum of the separate QAAP and TDDAP measured times. Thus, there appears to be no significant performance benefit to integrating adaptation logic in the target process when using a communication interface. Thus, for the aforementioned benefits of process modularization, separating the adaptation logic from target processes and supporting aspect-oriented processes appears practical.

Performance results show that the adaptation delays are potentially tolerable for non time-critical situations in dBPM, such as predictive adaptations. When reactive adaptations to executing processes in the cloud are involved, or when human actors cause adaptations and await responses, the delays may be unsatisfactory. Networking had a relatively minor effect on the overall operation duration. Available RAM may have limited PAIS performance, and different configurations and profiling could provide further insights.

In summary, the evaluation demonstrated that the solution concept is technically viable for non time-critical cloud scenarios and can be practically realized by extending a currently available adaptive PAIS. Further, adaptive process modularization and cloud distribution appears to currently have relatively little performance impact versus the cost of adaptive workflow operations. This could however change if optimization and performance issues are addressed.

# 6 CONCLUSIONS

A flexible cloud-capable approach for process adaptation called AProPro was introduced. Its feasibility was shown with a realization and a case study involving cloud-based adaptation workflows and measurements. Key adaptation capabilities towards dBPM were shown, including workflow-driven adaptations of workflows, aspect-oriented adaptations, self-adapting workflows, composability, process governance, and the cloud-based provisioning of adaptation processes with an Adaptations-as-a-Service (AaaS) paradigm. Proactive adaptations were applied in push fashion and pulled via self-adaptation. Measurements show that pursuing cloud-based distribution and adaptation modularization is likely not detrimental to performance, since adaptations had more impact.

The advantages of the AProPro adaptations for dBPM could be readily realized and benefit various domains such as healthcare, automotive, etc. For instance, a healthcare process could view allergies as an aspect and utilize an allergy adaptation workflow.

The solution faces issues analogous to those of aspect-oriented approaches, in that it may not be readily clear to process modelers which adaptations or effects may be applied in what order at any given workflow point. Thus, additional PAIS tooling and process simulation should support adaptation management, version and variant management, compatibility checking, and make adaptation effects or conflicts visible to process modelers.

Future work will investigate these issues, and involves comprehensive adaptation pattern coverage, empirical studies, optimizations, and heterogeneous PAIS testing. To achieve the dBPM vision, further work in the process community includes standardization work on interchangeable concrete process templates, repositories, and AaaS cloud APIs, which could further the provisioning, exchange, and reuse of workflows, especially adaptive workflows such as those of the AProPro approach, thus mitigating hindrances for widely modeling and supporting dBPM adaptation.

# ACKNOWLEDGEMENTS

The author thanks Florian Sorg for his assistance with the implementation and evaluation and Gregor Grambow for his assistance with the concept. This work was supported by AristaFlow and an AWS in Education Grant award.

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# APPENDIX

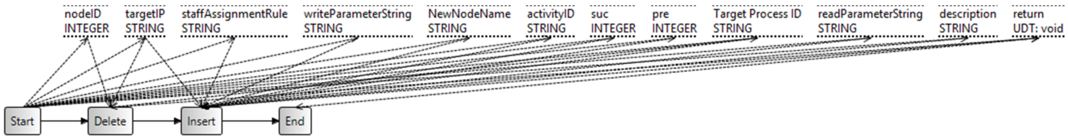


Figure 6: The Replace process fragment sub-process.

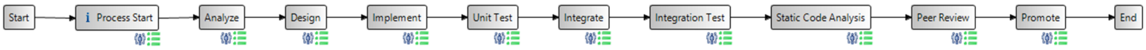


Figure 7: The unchanged Waterfall Process (WP).

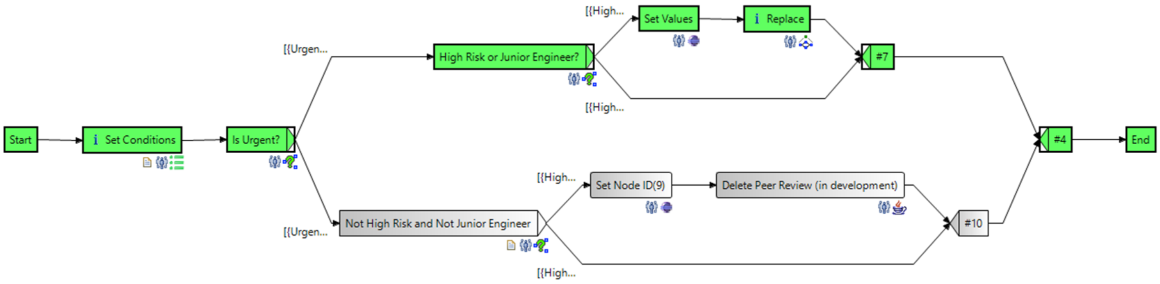


Figure 8: Quality Assurance Adaptation Process (QAAP).

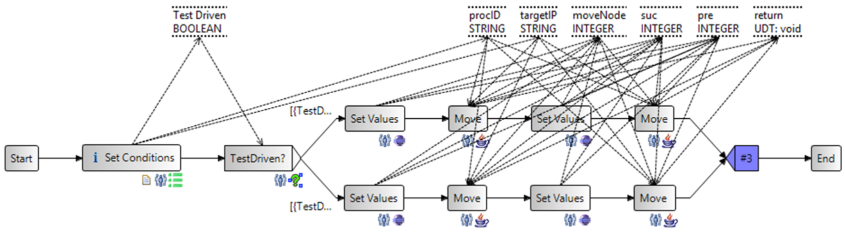


Figure 9: Test-Driven Development Adaptation Process (TDDAP).

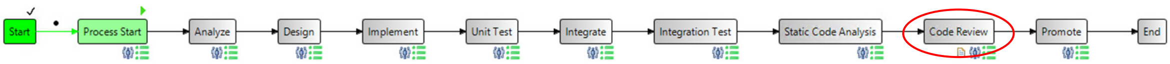


Figure 10: Waterfall Process after application of the Quality Assurance Adaptation Process.


Figure 11: Waterfall Process after application of the Test-Driven Development Adaptation Process.


Figure 12: Waterfall Process after application of both Adaptation Processes.

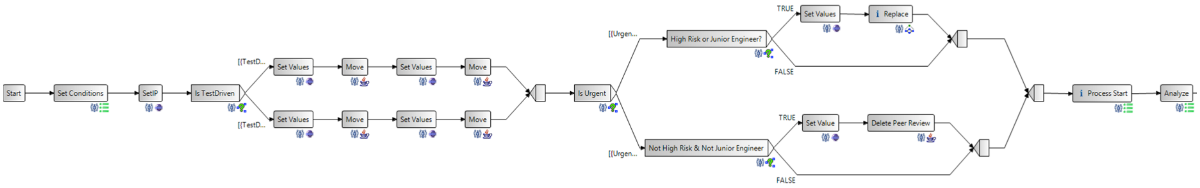


Figure 13: Self-adaptive Waterfall Process screenshot (continues to right as in Figure 7).

# Automated Process Model Discovery
## *Limitations and Challenges*

Norbert Gronau and Christian Glaschke
*Chair of Business Information Systems and Electronic Government, University of Potsdam, August Bebel Straße 89, Potsdam, Germany*
n.gronau@lswi.de, c.glaschke@lswi.de

Keywords: Process Mining, Process Model Discovery, Screen Capturing

Abstract: The implementation of business processes through the use of information systems (ERP, CRM, PLM and MES) has become a key success factor for companies. For further development and optimization of processes, many companies haven´t trusted processes for the analysis. Surveying as-is processes is complex and only possible by manual recording. To perform this task automatically the theory shows us different approaches (process mining, Application Usage Mining and Web Usage Mining). The target of the concepts and tools is to complement the process of continuous improvement in the company with meaningful process models, which can be reconstructed from protocols and user actions in the information systems. This article focuses on the limitations of these concepts and the challenges they present and gives an outlook on how future solutions must work to speed up the process of continuous improvement and to meet the challenges of heterogeneity in IS - architectures.

# 1 INTRODUCTION

For more than 20 years business process management has been the leading paradigm for organizing and restructuring corporations and public entities. Although all kinds of companies use business process management in certain areas, there are some challenges that require further analysis. To name only a few:

- Improving learning while performing a business process
- Making better use of person-bound knowledge that is generated in or used during the business process
- The establishment of PDCA cycles (plan-do-check-act) in process management, that enable the detection and subsequent correction of deviations without interrupting the business process
- Typically, business processes today are supported by enterprise systems like ERP, CRM or SCM. Normally, there are deviations between the intended process covered, the ERP and the actual process that is run in the company (cf. Gronau, 2015)
- The human interface is more important than ever in most business processes, despite automation. When the automated business process is interrupted, it is a human that has to decide how to propel the process further. The description of human interfaces is by no-way interoperable now.
- A better real world awareness of the objects of business processes (persons, information, cases, instances and customer materials) currently available, as well as approaches to integrate such information into the process, is more necessary than ever.

With respect to all these new challenges, detailed and purpose-specific modeling is the precondition for a purposeful analysis of the business process necessary for its improvement. The detection of business processes and the investigation into necessary attributes of all objects tends to be very time-consuming and is still incapable of being fully automated.

There are some approaches like process mining (cf. Van der Aalst, 2011) that can help identify process patterns or recurrent instances, but the mere act of modeling itself is one of the most challenging tasks. This process also heavily influences the quality of the results. Incorrect or missing attributes or objects mean that the purpose of analysis and the goal of the improvement cannot be reached.

Therefore, this paper describes ongoing research activities to determine an approach to automatically identify business processes and model them from the information that can be derived from information systems like ERP and CRM.

## 2 PROCESS MODEL DISCOVERY IN TIME FROM INTERNET OF THINGS

In this section, the topic of process model discovery in the area of a total digital integration is discussed. Current trends, such as the internet of things, industrial internet and digitalization (cf. Kagermann, 2014) are some of the main drivers for the development of new concepts and technologies in the area of business process modeling. At the center of these approaches lies the question of how it is possible to attain more efficient and transparent business processes. Hence, there is great demand for a current and trustworthy as-is process model (Houy et. al., 2011). Such a model is necessary to decide how to optimize or reengineer the process. Inquiries to determine as-is processes are very complex and labor intensive, and are typically carried out by manual forms of observation and data collection.

The main question of the present paper is: How can as-is processes in a corporation or a public entity be determined automatically for further analysis? This question has tackled in the past by using a variety of different viewpoints. For instance, there are techniques that use either certain properties of technologies (Web Usage Mining, cf. Zhong, 2013) or log files from enterprise systems to reconstruct as-is processes. This approach is called Application Usage and Process Mining. These tools and methods have to be integrated into what are today more heterogeneous application landscapes with variable technologies and application systems (cf. Huber, 2015). This trend will be even more intense in the future when more system elements from the Internet of Things are incorporated within the application landscape. Given that this development will occur in the near future, the research question of this contribution can be stated as follows: What kind of information about the environment and the enterprise are necessary in order to be able to discover processes automatically? To answer this question, current research approaches are described and their limitations analyzed. Additionally, solutions that allow for the use and analysis of the available data are outlined, and the existing challenges facing the development of a new method are illustrated. At the end, an outlook for further research is given.

## 3 EXISTING PROCESS DISCOVERY APPROACHES AND THEIR LIMITATIONS

A well-known approach for process discovery is the concept of process mining that was developed by Van der Aalst and his research group at Technical University of Eindhoven (The Netherlands). This approach uses log files from application systems (for instance ERP systems) to reconstruct processes. To be successful in that effort, the application system has to deliver the needed information in a specific manner (as shown in table 1).

Table 1: Example for a logfile.

| PID | Activity | Worker | Timestamp |
|---|---|---|---|
| 452 | registration | 55 | 2011-12-24, 11:10:21 |
| 452 | investigation | 56 | 2011-12-24, 11:15:21 |
| 452 | consulting | 33 | 2011-12-24, 12:17:10 |
| 452 | dismissal | 55 | 2011-12-24, 12:47:11 |
| 453 | registration | 55 | 2011-12-24, 11:16:35 |
| 453 | investigation | 56 | 2011-12-24, 11:27:12 |
| 453 | consulting | 12 | 2011-12-24, 11:52:37 |
| 453 | dismissal | 55 | 2011-12-24, 11:59:54 |
| 454 | registration | 55 | 2011-12-24, 11:11:21 |
| 454 | investigation | 55 | 2011-12-24, 11:15:21 |
| 454 | registration | 56 | 2011-12-24, 12:17:00 |

An important component of this listing of process instances is the process identification number (PID). This number is used to create a process diagram based on more than one process instance (cf. Van der Aalst, 2012). In the background, petri networks are used to be able to generate process diagrams, to describe the different conditions of the process and to create a graph for visualization and analysis (cf. Van der Aalst, 2011 & Accorsi et.al. 2012).

Another approach that uses more than one input source is Application Usage Mining. In this approach, the log files are complemented by additional data from the data-base of the information system: for instance on the users, workflows and functions of the system. This information is used to further enrich the models. In the background of this approach petri networks are also used to describe the logic of the process and to summarize the possible states of a system (cf. Kassem, 2005).

Both approaches rely on the assumption that a system that is able to generate data about business processes and to deliver log files in the necessary quality exists. This assumption is not valid for enterprises with a huge number of information systems, for instance best of breed solutions, federated ERP systems or combinations of different system classes (PLM and ERP and DMS and MES) that are used together in the business process. Furthermore, customizing the application systems is very time consuming and a very high level of expertise is required. One feature that complicates this approach is that the functions executed by the application system are used as a first hint for classification and instance creation. Hence, the relevant process tasks and functions have to be known before the customizing of log files can take place.

Another possibility to record the interactions between user and system are log files of web-based systems. This approach is called Web Usage Mining. Here the access point for the process recording is the technology used (PHP, HTML, Javascript, ...). As in the process mining approach, the server can record user requests and results into logs. The session ID is used as process ID (cf. Bhart, 2014). This principle is typically used for analyzing the user‘s behavior and not for reconstructing business processes, but an adaptation for web-based application systems seems to be at least possible.

Starting from the preconditions that for a successful execution of business processes more than one application system and different technologies are used and that some of the tasks are performed outside of the information systems, a new approach is necessary to be able to automatically discover and record business processes.

To sum up, it can be said that existing approaches for the data collection either have specific knowledge about the process or concentrate on only one application system or one single technology. As information about real objects, locations and movements are not taken into account, these methods can only achieve a limited degree of accuracy. Hence, we formulate another research question: How can the user and his surrounding likewise be taken into account for process model discovery?

# 4 IDENTIFIED POSSIBILITIES FOR DATA CAPTURING

This section shows possibilities to collect data from performed processes without being dependent on specific application systems or technologies. Another aim of this section is to describe which information user and environment can deliver and how this information can be captured.

## 4.1 Screen Capturing and Optical Character Recognition

A main point of criticism about the approaches presented in section 3 is that a lot of work is necessary to configure the log data, and that meta information for the enrichment of log files in a structured manner has to be available. To obtain this information without any knowledge about the business process, an approach is needed which works independently from application systems. Application systems are ideally closed systems with complex interactions with clients that use different data formats.

There is only one object that shows all the interactions between user and system, the screen. To be able to use this valuable source of information, screen captures can be analyzed by an OCR software (Shekappa et. al., 2015). From this information a matrix can then be derived (table 2). The lines are the clients where the software captures the screen content. The columns are the different points in time when the screen capturing took place. Every cell is the result of an OCR recognition f(t) at a certain moment (for instance t1). Available screen capturing software is also able to capture the cursor positions and mouse clicks of the user (cf. Huang et. al, 2011 & Johnson et. al., 2012). Therefore, it is also possible to analyze table cells in an application system selected by the user. This approach delivers data about the interactions of the user with a terminal that is sorted by date but unstructured. It is also possible to find out the cursor position,

Table 2: Results table for OCR recording.

| | t1 | t2 | t3 | t4 | t5 | t6 | t7 | t8 | t9 | t10 | t11 | t12 | t13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Client 1 | f(t1) | f(t2) | f(t3) | f(t4) | f(t5) | f(t6) | f(t7) | f(t8) | f(t9) | f(t10) | f(t11) | f(t12) | f(t13) |
| Client 2 | f(t1) | f(t2) | f(t3) | f(t4) | f(t5) | f(t6) | f(t7) | f(t8) | f(t9) | f(t10) | f(t11) | f(t12) | f(t13) |
| Client 3 | f(t1) | f(t2) | f(t3) | f(t4) | f(t5) | f(t6) | f(t7) | f(t8) | f(t9) | f(t10) | f(t11) | f(t12) | f(t13) |
| Client 4 | f(t1) | f(t2) | f(t3) | f(t4) | f(t5) | f(t6) | f(t7) | f(t8) | f(t9) | f(t10) | f(t11) | f(t12) | f(t13) |
| Client 5 | f(t1) | f(t2) | f(t3) | f(t4) | f(t5) | f(t6) | f(t7) | f(t8) | f(t9) | f(t10) | f(t11) | f(t12) | f(t13) |

and to analyze which fields were selected by the user and which functions were performed.

## 4.2 Operating System Information

Another point of criticism concerning the approaches presented in section 2 is the exclusive focus on application systems. Other software running on the computer also delivers data that can be used for the reconstruction of processes and the generation of meta information.

Aside from the user entries, the operating system can also deliver other valuable information. This might include log-in credentials, the program used and the data entered. Additionally, the operating system is responsible for file operations and network access (cf. Tanenbaum, 2003). Using this information it is possible to determine which file was opened or processed.

## 4.3 Process ID in Application Systems

The process ID makes a substantial contribution to the discovery of a process. It makes it possible to distinguish between different process instances. From that structure, in turn, a process model can be reconstructed. In application systems, a huge set of distinct numbers for different kinds of data and levels of detail exist. Execution data exist for the accomplishment of business processes. This data, for instance, reveals the change of storage data when a delivery document changes the stored amount of an item by a booking process. This delivery document has a unique number and also points to its logical predecessors. The offer number can be found in the order; the order number is mentioned on a factory order or on a delivery document. The document flow that can be created from these numbers can be reconstructed or read from the leading application systems supporting this process. Additionally, these numbers are also available when corresponding with a client, for instance ticket numbers or invoice numbers. Master data identifies a business object (product resource, storage facility) uniquely by a number. In some cases, not only are the products identified, but also the object instances. Therefore, a serial number or batch number is used. These numbers are typically printed onto the product and are used for traceability of every single item or batch job in logistics and manufacturing.

## 4.4 Tracking of Business Objects

Another approach to collect information about the environment and the user utilizes technologies to spatially locate users and objects. Different approaches, such as RFID or GPS, exist for this purpose. A movement profile can be derived from this data. These movements can be used to follow processes when an object is moved and to define interactions between users and business objects (cf. Sultanow, 2015 & Gronau, 2014).

## 4.5 Summary

Four approaches can be used to collect data about business processes in corporations. The next task is to use that information to reconstruct the underlying business processes.

# 5 CHALLENGES DURING THE DEVELOPMENT OF A METHOD

Combining the information from the different approaches in section 4 leads to different challenges for further research. In this section, the problems are elaborated with the help of an exemplary scenario. This scenario is described at first to depict the challenges. A special emphasis is put on the aspects of the existing approaches Process Mining, Application Usage Mining and Web Usage Mining that constitute weaknesses.

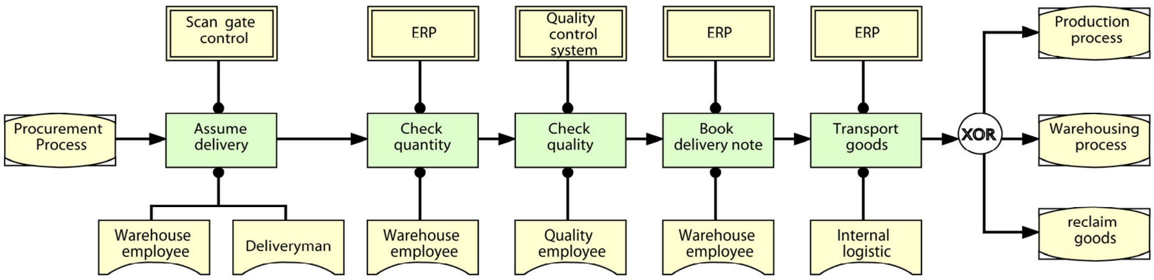


Figure 1: Product entry process.

## 5.1 The Example of the Data Entry Process

To be able to describe the challenges a scenario was developed, in which a product entry process is performed. In figure 1, the process is illustrated in the KMDL process view (Gronau, 2005).

The process goes as follows: after a successful order from the procurement process (process interface), the goods are delivered. The delivery is accepted and driven through a scan gate. The information system „scan gate control" shows the warehouse employee (role) the listing of the delivered parts on a client computer and shows the serial, order and supplier numbers from the RFID tags of the packages. After checking that information, the warehouse employee approves the delivery document for the delivery man and in the scan gate control Software the parts list. The data from the scan gate control system is entered into the ERP system as a quality control system. In the ERP system, a new bill of delivery is generated that contains the articles and their amounts. The warehouse employee unpacks the goods and gets the bill of delivery in the ERP system in order to check the quantities. After confirming the amount, the ERP bill of delivery is handed over for inspection to the Quality Control System, which creates a test order, which includes the different properties of the articles. The Quality employee checks the properties per serial number and deposited a test result. Some parts are identified as unsuitable. This has to be entered into the quality control system. Most articles pass the amount check successfully. Acknowledging that the ERP system has been checked automatically produces the results of the quality assurance task and generates a storage location for every serial number of the delivered goods in the bill of delivery. Good parts are now transported to the manufacturing storage, bad parts into a reclaim storage yard. Articles marked as consumables are stored in the warehousing process. In process step book delivery note the articles in different charge carrier / transport units are separated. Then, the delivery will be booked. The ERP system generates from a transfer order, which is processed by the logistics department. Hence, the goods are stored in different locations.

## 5.2 Challenges of Automated Process Model Discovery

The first challenge for the approaches from section 3 is to recognize that the procurement process is the trigger for the warehouse entry process. In the process "assume delivery," the order number is the only connection between these two processes. This connection has to be recognized and assigned to the order process. This is the main result to expect from the method to be developed. Therefore, the recognition mechanism has to find out that the same order number is now used during the delivery, and has to interpret this as a unique number.

Using the statements above we can formulate some requirements for the necessary recognition mechanism.

The method has to reliably find out the unique identifiers by screen capturing and OCR.

A second challenge can be derived from the "assume delivery" process. Here it is necessary to find out that the serial numbers indicate the different flows of goods. To achieve this, the products that are equipped with RFID tags at different locations (storage, quality control, ...) show the serial numbers and the current location belonging to that serial number. Of course, the information about the locations of the RFID reader stations must be known. Second challenge: The method must combine information from the screen capturing with the determined location of the goods.

Another challenge is the assignment of roles and information systems to the steps of the process. The warehouse employee logs himself into the system with his mobile device and connects himself to the scan gate control system. The operating system then captures the user group or the log-in name. With other information systems the process is performed in a similar manner. The operating system registers the usage of the scan gate control software and allocates this software to the process. The only role in the exemplary process that cannot be captured in this manner is the delivery man. Third challenge: The method must be able to recognize the external and internal roles involved in the process.

The next challenge is it to differentiate between the different process steps. In the example, the differentiation between the process steps “assume delivery” and “check quantity” can be performed by different information systems. When the process transfers from “check quantity” to “check quality”, different roles and different systems allow one to find out that different process steps are performed. A differentiation on that level is at any rate impossible. An example of this can be seen in the work of a sourcing employee who works with an ERP system and does everything in the sourcing process, from ordering to invoice checks, on his or her own. Fourth challenge: The method must discover the different process steps and be able to see the limit of one process step and the beginning of another one.

The fifth challenge is to find out the description of the process. To that end, a lot of information is collected from OCR or screen capturing, but their interpretation is difficult. An example is the “check quantity” process, and the question: how can we derive that term? One approach would be to assign the function to the location; another approach would be to use the window title of the ERP system (“delivery note”). Sometimes this task can be done by manual configuration, or by screen capturing. The fifth challenge is, therefore, that the method must be able to determine the name of a process step.

The sixth challenge is to recognize different target locations (storage locations in the logistic process) from logistics and from the transport of goods. Therefore, these different locations have to be distinguished in the process by using different process interfaces. To meet this challenge, the master data of the storage in the warehouse management system could be used to help understand the structure of the storage groups and their functionality in the process. Another possibility is to assign this information to the different locations. When this information is available for differentiation, the process interfaces into the storage area can be reconstructed. The sixth challenge is: The method must have knowledge that specifies the environment.

# 6 CONCLUSION AND OUTLOOK

The contribution has shown that an automated discovery of process models is possible when some new approaches are applied. The investigation of current approaches showed that systems and technologies deliver valuable information about the process flow, but a configuration for a case of specific use is necessary. The main gap in the research is the lack of consideration of human tasks and environmental data.

For the research task to develop a new integrated approach, a couple of challenges must be dealt with. One of the most important requirements of a new method is to see the corporation and its data sources in an integrated manner. Another important topic is the collection of data according to location, time and their connection to the process model. No satisfactory answer could be given to the research question concerning which information about the user and the environment has to be collected in order to be able to sufficiently discover process models. On one hand, information about location must be available (for instance which task is performed where), while on the other hand, the master data that holds that information has to be investigated. In any case, the demand for and benefit of that kind of input can be shown. Finally, there remains the question of how the recognition mechanism uses semantic techniques. Here it might be possible that the user has to assist the recognition mechanism to describe the process models.

An open issue after creating process models is to interpret these semi-formal models. To reach an understanding about a process solely by using a model is very difficult. The authors thinks that human beings, too, will have to participate in that process in the future.

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# Towards Business Process Modeling for Knowledge Management

Mariam Ben Hassen, Mohamed Turki and Faïez Gargouri
*University of Sfax, ISIMS, MIRACL Laboratory - B.P. 242, 3021 Sfax, Tunisia*
*{mariembenhassen, mohamed_turki}@yahoo.fr, faiez.gargouri@isims.rnu.tn*

Keywords: Knowledge Management, Knowledge Identification, Sensitive Process, Core ontology of organization's processes Business Process Modeling.

Abstract: In an organizational context, the characterization and modeling of the business processes are necessary to localize knowledge that need to be capitalized. In this paper, we propose a new multi-dimensional meta-model of business processes modeling for knowledge management, entitled BPM4KI (Business Process Meta-Model for Knowledge Identification). This meta-model aims to enrich graphical representation of business process by integrating all aspects of process modeling: the knowledge, informational, functional, behavioral, organizational and intentional perspectives. It helps to identify and localize the crucial knowledge that is mobilized and created by these processes. Moreover, it has been illustrated through a medical process in the context of the organization of protection of the motor disabled people of Tunisia.

## 1 INTRODUCTION

More and more organizations are becoming aware of the importance of tacit and explicit knowledge owned by their members which corresponds to their experience and accumulated knowledge about the firm activities. Thus, in order to improve their performance, such organizations become conscious of the necessity to effectively identify, preserve, share and use the organizational knowledge mobilized and created by their business processes (BPs). This knowledge represents a competitive, decisive and lasting advantage and a source of wealth to be valorized.

According to the literature review, in term of the process view several researchers and practitioners have been focusing on the management of the BPs. Particularly in the information systems engineering, many works have been developed ((Curtis et al., 1992) (Melao and Pidd, 2000) (Nurcan et al., 2005) (Mili et al., 2010)) and aim at modeling, improving and optimizing the BPs. In accordance with the knowledge management view, few methods focusing on process analysis for knowledge identification have been proposed by researchers on KM ((Grundstein, 2000) (Tseng and Huang, 2005) (Saad et al., 2009) (Turki et al., 2014a; 2014b)). There have been several attempts to integrate the domain of KM and BPM. We quote process oriented Knowledge Management approaches ((Suyeon et al., 2003) (Gronau et al., 2005) (Heisig, 2006) (Zhaoli et al., 2008)) and knowledge oriented BPM approaches ((Zhang and Li, 2005) (Woitsch and Karagiannis 2005) (Weidong and Weihui, 2008) (Supulniece et al., 2010) (Bušinska and Kirikova, 2011) (Bušinska et al., 2011) (Sultanow et al., 2012) (Liu et al., 2012) (Netto et al., 2013)).

However, the integration of BPM and KM has not yet received sufficient attention. In fact, the knowledge dimension (i.e. the knowledge used or generated by activities, the sources of knowledge, explicit knowledge, tacit knowledge, individual and collective dimension of knowledge/activities, etc.) needed for BPM is not explicitly represented, integrated and implemented in BP meta-models.

The current paper proposes a new multi-perspective meta-model of the BPs for KM, entitled BPM4KI (Business Process Meta-Model for Knowledge Identification). This meta-model aims to enrich the graphical representation of BPs and improve the localization of crucial knowledge (i.e. knowledge on which it is necessary to capitalize) mobilized and created by these processes. In fact, more the organization's processes are sensitive, more they can mobilize crucial knowledge.

BPM4KI covers all aspects of BPM and KM. It consists of six perspectives: the functional, organizational, behavioral, informational, intentional and knowledge perspectives. The first five perspectives are inherited from (Nurcan, 2008) as typically oriented towards business modeling and enriched by some new concepts defined by the core ontology of organization's processes (COOP) proposed by Turki et al. (2014b). We extend the above-mentioned perspectives with the « knowledge perspective » in order to address all relevant issues related to KM.

Furthermore, we intend to integrate and implement the proposed BPM4KI meta-model in the Business Process Modeling Notation (BPMN 2.0). In practice, the result of the BPMN 2.0 extension will be used to well modeling the sensitive business processes (SBPs) which are likely to mobilize crucial knowledge.

The remainder of this paper is organized as follows: Section 2 presents related work to analyze existing work on BPM for KM. Section 3 describes the proposed BPM4KI meta-model. Section 4 illustrates the application of BPM4KI based on a real case study. Section 5 concludes the paper and underlines some future research.

## 2 RELATED WORK

In this section, we present main methodologies focused on BPM for knowledge identification which have been proposed by researchers on KM. We consider the Global Analysis METHodology (Grundstein, 2000), the identifying crucial knowledge methodology (Saad et al., 2009), the Sensitive Organization's Process Identification Methodology (Turki et al., 2014a), as relevant to the BPM-KM area. We have selected to discuss them in this section, following a literature survey.

The Global Analysis Methodology (GAMETH) proposed by Grundstein (2000) comprises three main phases gathering the following steps: (i) «Identifying the sensitive processes» specifies the project context, defines the domain and limits of the intervention and determines the processes targeted to be deeply analyzed. According to this author, "*A sensitive process is a process, which represents the important issues which are collectively acknowledged: weakness of the process which risks not attaining its objectives, obstacles to overcome; (iii) difficult challenge to take in charge; (iv) produced goods or services which are strategic in regard to the organization's orientations*". (ii) « Identifying the determining problems» aims at distinguishing the problems which weaken the critical activities, (i.e. the activities that could endanger the sensitive processes due to dysfunctions and constraints which affect it and generate determining problems). (iii) «Identifying the Crucial Knowledge» is intended to define, localize and characterize the knowledge to be capitalized.

The methodology for identifying the crucial knowledge proposed by Saad et al. (2009) is based on the GAMETH framework. It aims at capitalizing the knowledge mobilized and created in the course of a project. It is composed of three phases: (i) Determining «Reference Knowledge»; (ii) Constructing Preference model; (iii) Classifying «Potential Crucial Knowledge».

Turki et al. (2014a) and Turki et al. (2014b) have in depth dealt with the issue of identifying « Sensitive organization's processes ». They have proposed a new multi-criteria methodology entitled SOPIM (Sensitive Organization's Process Identification Methodology) and a Core Ontology of Organization's Processes (COOP) to help the assessment and identification of SBPs. SOPIM is composed of two main phases: (i) Construction of the preference model, and (ii) Exploitation of the preference model (decision rules) to classify the «Potential Sensitive organization's processes».

Each approach mentioned above, defines a set of phases for modeling and identifying the SBPs. However, we note that the BPM step has not been studied in depth. In particular, we have noted the lack of expressiveness BPM formalisms that explicitly integrate all relevant aspects related to knowledge dimension and other aspects which cover the BPM. In order to remedy for this lack, this paper aims to extend and consolidate previous work made by Saad et al. (2009) and Turki et al. (2014a) in order to cover the gap between BPM and KM and address an important problem that is not often dealt with KM methodologies. Exactly, our mission aims to enrich and optimize the operation of "modeling and representation of identified SBPs" in order to increase the probability of localizing and identifying the crucial knowledge. This reduces the cost of the operation of capitalizing on knowledge.

The first step to address existing limitations and achieve this objective is the specification of a precise conceptualization, together with a subjacent representation notation, that precisely describes all SBP essential characteristics as well as the dynamics with which knowledge is mobilized and created during a SBP, is still an open issue. In fact, this is not a trivial task, since SBP involve many subjective and complex concepts that are subject to different interpretations. We briefly describe in the following the most important specific particularities for SBPs modeling, highlighting its key features.

An SBP is a particular type of BP. It has its own characteristics that distinguish it from BPs processes (see (Turki et al., 2014b). we deduce and adopt for our notion of SBP the following characterization. A business process is described as « sensitive », if at least one of the following requirements is fulfilled: (i) It mobilizes crucial knowledge (which is considered as immaterial resource). It contains activities based on acquisition, sharing, dissemination, storage, creation, (re)use of organizational knowledge, and collaboration among participants. (ii) It is very dependent on the tacit and explicit knowledge (individual and collective) embedded in the stakeholders' minds (experts, specialists, etc.), and in the actions. (iii) It is very complex, with a high number of (individual and collective) actions which are flexibles, high number of critical activities (which mobilizes very important organizational tacit knowledge, high degree of tacit knowledge held by a very small number of experts or individual /collective knowledge poorly mastered to solve critical problems, diversity of information and knowledge sources as well as large flow of knowledge, etc.). (iv) It mobilizes a large number of business domains / skills (in terms of internal and external organization unit involved in the process). Its execution involves many participants and the assistance of many experts, with different experience and expertise levels. (v) It has a high number of collaborative activities that mobilize, share and generate new, very important organizational knowledge (tacit and / or explicit) created at the time of interaction among agents. So that, it focus on the dynamic conversion of knowledge (Nonaka & Takeuchi, 1995). (vi) It possesses a high degree of dynamism in the objectives' change associated to it. The influence of intentions and experiences of the agents in decision making is very important. (vii) Its contribution to reach the organization's strategic objectives is very important. In short, we can conclude that flexibility, efficient collaboration and effective knowledge management are the key requirements for specifying SBPs. Due to those characteristics, organizing the knowledge in SBPs and building a SBP model are not an easy task. The selection and adoption of a suitable BPM formalism for SBPs modeling is critical, although challenging. In this context, several BPM approaches have been proposed in information system engineering (particularly in BPs engineering). Some traditional BPM formalisms that are largely used in current research and practice scenarios in organizations like Event Driven Process Chain (EPC) (Korherr and List, 2006), UML 2.0 Activity Diagrams (AD) (OMG, 2011a), Process Specification Language (PSL) (Schlenoff et al., 2000) and Business Process Modeling Notation (BPMN 2.0) (OMG, 2011b) have been adapted to allow the explicit representation of the intrinsic elements of knowledge within BPs, but they do not include all the required features necessary to describe a SBP. It is obvious that these formalisms are suitable for process perspective representation, but poorly present data, information and knowledge (flows) which are not be represented separately and clearly in the process models. However, this distinction is useful and essential for our modeling context. Besides, the literature shows a set of formalisms dedicated to knowledge- intensive processes representation (Gronau et al., 2005) (called also Process-oriented knowledge modeling approaches) that focus on storing and sharing knowledge, including Business Process Knowledge Method (BPKM) (Papavassiliou et al., 2002), Knowledge Modeling Description Language (KMDL 2.2) (Gronau et al., 2005), Oliveira's methodology (Oliveira, 2009), Notation for Knowledge-Intensive Processes (NKIP) (Netto et al., 2013), etc. Some major limitations can be emphasized in this category. One the one hand, these approaches did not experience a wide adoption among organizations and are very incipient. On the other hand, they lack the ability in an adequate manner to model the process perspective (the structural, organizational and informational dimensions). Moreover, some proposals do not explicitly differentiate tacit knowledge from explicit knowledge. In addition, there are deficits in the conversion of the knowledge types (such as internalization, externalization, socialization and combination) (Nonaka & Takeuchi, 1995) and the person-related knowledge modeling that are relevant in SBPs due to, for instance the high degree of tacit knowledge developed and exchanged among agents through inter-organizational collaboration.

Furthermore, following the study of BPs meta-models and ontologies associated with the main BPM formalisms, we notice that the defined concepts -actions specification (Process, Activity, Sub-process, Task) do not take into account the individual / collective dimension of the actions. However, taking into consideration such a dimension is very important in our context given that we are interested in the localization of knowledge mobilized to achieve the process. This knowledge taken in the action may be either individual (tacit or explicit) or collective and organizational (tacit or explicit). Despite it mobilizes crucial knowledge within an organization and their key role for organizational KM, existing BPM formalisms have shortcomings in their ability to represent SBPs. None of those proposals include or address conveniently all or at least most of the SBPs particularities and characteristics as well as the essential issues of KM. This leads to ambiguity and misunderstanding of the developed SBPs models. Based on the results discussed in this section, the SBPs representation is a lot more difficult. So, such formalism should take into account all semantic dimensions and criteria enabling to characterize in depth the notion of process. Therefore, there is a need to precisely define the specification of a SBP, including the concepts and relationships between them that adequately address the knowledge within their actions and all SBP essential aspects.

In order to propose a solution that is capable of explaining a SBP, considering both the knowledge within their actions and other relevant aspects aimed to meet the new requirements of BPM, we propose a meta-model of the BPs for knowledge identification, called BPM4KI, to characterize the concepts useful for the modeling and analysis of SBPs, in order to locate the knowledge mobilized and created by these processes, which may be crucial.

# 3 BPM4KI: A META-MODEL OF THE BUSINESS PROCESS MODELING FOR KNOWLEDGE IDENTIFICATION

In order to localize and identify in depth the crucial knowledge, we propose a new Business Process Meta-model for Knowledge Identification (BPM4KI). We have summarized and structured the main concepts (of the field of BP and KM) that we judge essential and relevant for the characterization and modeling of the SBP in a meta-model for synthesis, represented as a UML class diagram.

The generic meta-model we have developed is based on the core ontology COOP proposed by Turki et al. (2014b) and categorized according to the framework of Nurcan (2008). COOP provides taxonomy of concepts which are defined in a rigorous and consensual way, we quote: Action, Action of Organization, Individual Action, Action of Collective, Collective, Organization, Distal Intention, Deliberate Action, Sensitive Process, Critical Activity, etc. While the Nurcan's framework consists of five perspectives, each one of them focuses on a process aspect: functional, organizational, behavioral, informational and intentional. As these perspectives do not capture all relevant aspects related to knowledge dimension, we have extended the abovementioned framework with a further perspective, namely the knowledge perspective. It should be noted that Knowledge might be considered as one of the business process dimensions, because knowledge is related to action, it is implemented in the action, and is essential to its development (Grundstein, 2000). It is created as a result of process execution, knowledge is used to perform a process, and it is distributed among process participants (Heisig, 2006).

Figure 1 presents BPM4KI in terms of classes and relationships between classes. The defined concepts that make up the COOP ontology are marked in gray in the meta-model. In the following, we describe the six perspectives contained in the BPM4KI meta-model.

The ***Functional Perspective*** represents the BP elements which are being performed (i.e. activity, sub-process and tasks). Hence, as illustrated in Figure 1, the BPM4KI meta-model part that can be used to model this perspective is inspired by Turki et al. (2014b). It regroups generic classes related to (inheriting from) the `Action` meta-class (With respect to our notation, the informal labels on BPM4KI concepts appear in the text in the `Courrier new` font with First Capital Letters). An `Action` can be individual or collective. An `Individual Action` *is carried out* by (*hasForAgent)* a `Human`. While a `Collective Action` is *carried out by* a `Collective`, is *controlledBy* a `Collective Intention` and *hasForProperPart* at least two `Individual Action` contributing to it. A `Business Process` is an `Action of Organization` (which in turn a specialization of `Collective Action`) carried out by a group of individuals affiliated with the organization. Any `Business Process` *hasForproperPart* a set of `Organizational Activities` coordinated and undertaken according to an intentionally defined objective. An `Organizational Activity` can be either an `Organizational Unit Action` or an `Organizational Individual Action` according to whether their agent is

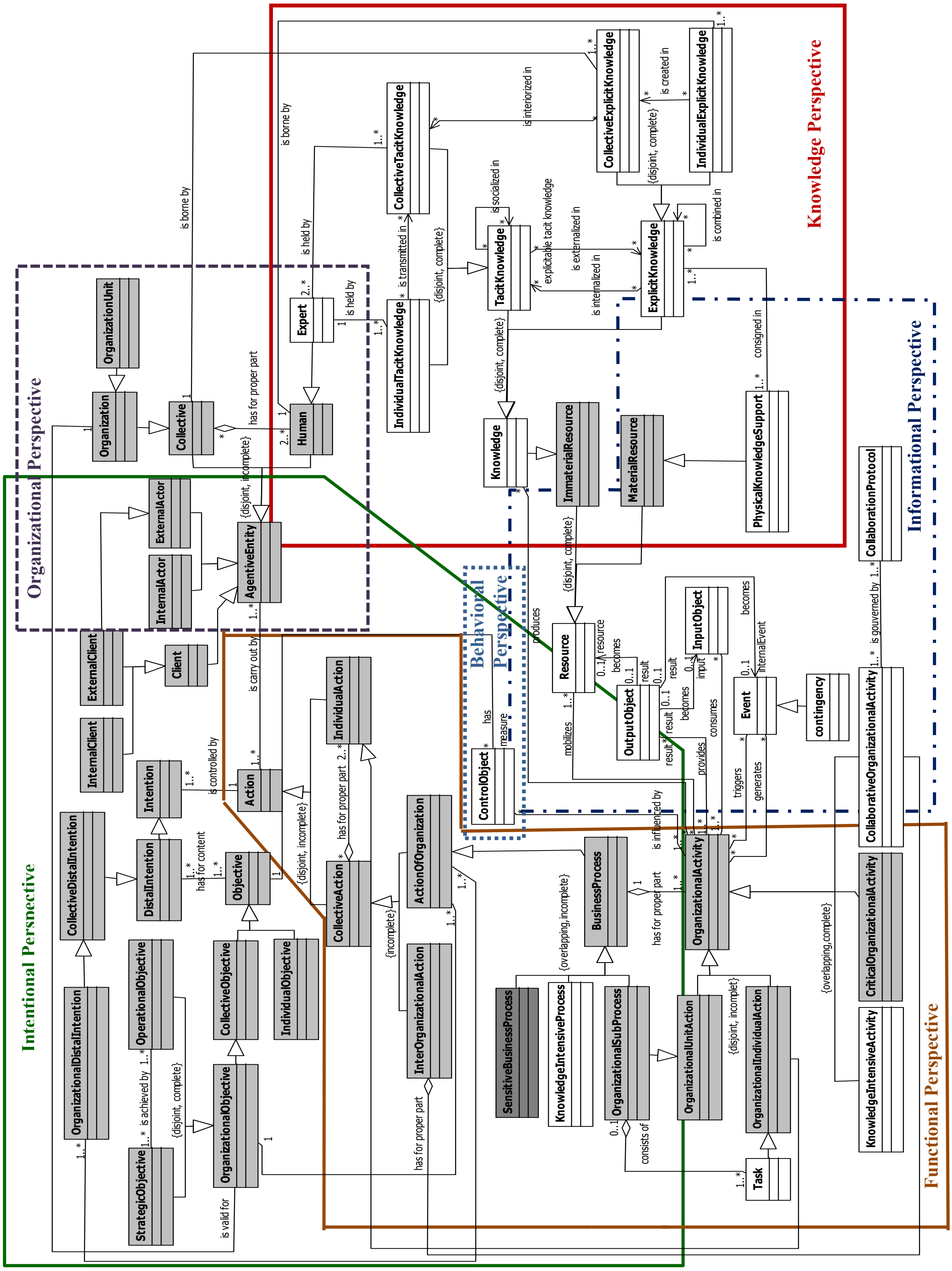



Figure 1: A multi-dimensional meta-model of the business processes for knowledge identification “BPM4KI” *(categorized according to six perspectives)*.

performed by an Organization Unit or a Human affiliated to the Organization). An Organizational Sub-Process is an Organizational Unit Action which *is a proper part* of a Business Process. Furthermore, an Organizational Activity can either be qualified as a Critical Organizational Activity, or as a Knowledge Intensive Activity or Collaborative Activity. They can also be described as critical.

The ***Organizational Perspective*** represents the different participants (agents) invoked in the execution of process elements as well as their affiliation. The basic element of this perspective is Agentive Entity. An Agentive Entity is an entity which has a capacity to carry out (and therefore to repeat) Actions (in particular deliberate actions). It can be specified in the form of a Human, an Informal Group, or an Organization, internal or external to an Organization. Any Collective Action *hasForAgent* a Collective.An Organization is a Collective (structured and formal) which can carry out an Action of Organization.

The ***Behavioural Perspective*** basically describes the control flow and the logical sequence of elements to be executed in a process. It includes synchronization, decision- making conditions, entry and exit criteria, sequence, iteration, etc. The basic element of this perspective is Control Object (such as pre-conditions, post-conditions, triggers, performance indicators, etc.).

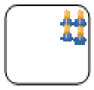
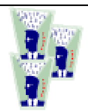
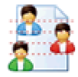
The ***Informational Perspective*** describes the informational entities which are generated, consumed, or exchanged within a process or an activity as well as their structure and the relationships among them. This perspective contains mainly the generic classes Resource with its derived class Material Resource (and the specialization class Physical Knowledge Support), InputObject, OutputObject, Event, and Collaboration Protocol. In fact, for its accomplishment, an Organizational Activity uses Input Objects (materials, data or information), mobilizes Material Resources and/or Immaterial resources to produce Output Objects (data, information, services, results, outputs) and under the influence of Control Objects. It can be triggered by Events, which can in turn produce Events. A Contingency is an external and unpredictable event that influences the process execution (the elements produced or handled and decisions made) (França et al., 2012). It should be emphasized that data object and information object (which is stored by electronic media or written down in documents) form the basis for knowledge sharing and the creation of new knowledge objects.

The ***Intentional Perspective*** describes major BP characteristics and captures important BP context information (such as goals and their measures, strategies, the deliverables, the process type and the customer), in order to ensure the BP flexibility (Nurcan, 2008) (List and Korherr, 2006). The meta-model elements of this perspective are inspired by the COOP ontology (Turki et al., 2014b). It comprises mainly the central concepts Distal Intention, Objective, Organizational Objective, Sensitive Business Process, Output Object (deliverables), Control Object (performance measures) and Client.Each Business Process meets an Organizational Objective (which is an Objective) intentionally defined. A Distal Intention *hasForContent* an Objective. So, this process *isControlledBy* a Distal Intention, in particular an Organizational Distal Intention (which is a Collective Distal Intention). Then the Business Process is a Deliberate Action (Turki et al., 2014b). Every OrganizationalDistal Intention *hasForContent* an Organizational Objective. Depending on whether the content of a Collective Distal Intention or an Individual Distal Intention, an Objective can be either an Individual Objective or a Collective Objective. A Collective Objective *isValidFor* an Organization, then it is an Organizational Objective which can be either a Strategic Objective or an Operational Objective. Each Business Process must provide a result which has a value to the organization's Clients. (It is therefore a Culminated Process (Turki et al., 2014b). Then, Output Object (i.e. deliverables which are either services or products) can be located in the behavioral perspective as well as in intentional perspective. A Business Process satisfies one or more Clients, which are either internal or external to the Organization. A Business Process has a certain process type. In COOP, the authors (Turki et al., 2014b) distinguish different categories of BPs classified according to several dimensions: *granularity*, *value*, *affiliation*, *repetition* and *piloting*. For instance, according to the level of process granularity, we distinguish between `First Level Process` and `Organizational Sub Process`. Depending on the affiliation dimension of the agents operating in the process, we specify three process classes: *Internal Process*, *External Process* and *Partial External Process*. Additionally, we propose to distinguish two other categories of BP according to the *complexity* dimension: `Sensitive Business Process` and `Knowledge Intensive Process`. Their objectives are frequently changed.

Last but not least, the ***Knowledge perspective*** provides an overview perspective of the organizational and individual knowledge mobilized by an organization as well as the knowledge flow proceeding within and between organizations. It describes all relevant aspects related to KM. Then, it emphasizes knowledge collection, organization, storage, transfer, sharing, creation and reuse among process participants. Therefore, it specifies the different opportunities of knowledge conversion. This perspective distinguishes also between knowledge used to perform (BP) and knowledge created as a result of BP activities. It identifies the different types of knowledge (tacit/explicit dimension) mobilized and created by each type of activity, the different sources of knowledge, their localization (where they are created or stored and where they are used), tacit and non-explicitable knowledge, persons holding them, their nature and their organizational coverage (individual/collective dimension).The basic elements of this perspective (Figure 1) are `Immaterial Resource`, `Knowledge`, `Tacit Knowledge`, `Explicit Knowledge`, `Physical KnowledgeSupport and Expert`. An `Organizational Activity` mobilizes and produces different types of `Knowledge` (which is an `Immaterial Resource` of an organization). `Knowledge` comes in two dimensions explicit and tacit. Each kind of `Knowledge` can be held individually or collectively and is localized in different knowledge sources. `Tacit knowledge` originates and is applied in the minds of the owners of knowledge and hence it is almost impossible to put into a document or a database, as well as difficult to communicate and share. `Explicit knowledge` is typically structured and retrievable and often becomes embedded in documents, repositories, organizational routines, practices, norms, etc. Organizational collective knowledge integrates a company's experiences, company-specific knowledge, culture, decision-making procedures, the detail of BPs, etc. An `Individual Tacit Knowledge` *is held by* one `Expert` (a `Human` who carries out `Actions` with high levels of expertise, creativity and). A `Collective Tacit Knowledge` *is held by* at least two `Experts` (which constitute a `Collective`). An `Individual Explicit Knowledge` *is born by* a `Human`. A `Collective Explicit Knowledge` *is born by* a `Collective` (i.e. an `Organization`). `Explicit` Knowledge is often stored in one or more `Physical Knowledge Support` (i.e. media, as documents, computer system, etc.) enabling their dissemination, sharing and use. A `Physical Knowledge Support` is a `Material Resource` (informational resource), having source of knowledge information interpreted and mobilized by the actors during the execution of their activities. Then, this concept can be located both in the knowledge and Informational perspectives. A `Collaborative Organizational Activity` mobilizes and produces new `Collective Knowledge` by a set of interactions (between individuals). A `Critical Activity` mobilizes different types of `knowledge`: (i) imperfect individual and collective knowledge (tacit or explicit) (i.e. missing, poorly mastered, uncertain, etc.) which are necessary for solving critical determining problems; (ii) important, diverse and heterogeneous knowledge recorded on multiple sources of knowledge (dispersed and sometimes lacking accessibility); (iii) expertise and/or rare knowledge held by a very small number of experts (which have high levels of expertise, creativity and innovation); (iv) very important tacit organizational knowledge, often linked to competences, abilities and practical experiences of their holders. This activity is based on several experiments. Besides, it may threaten `Sensitive Business Processes`. It should be noted that some concepts are shared by different perspectives. For instance, the `Collaborative Activity` concept belongs to all perspectives.

Once modeled, the BPs can be graphically represented, using BPM formalism in order to localize the knowledge that is mobilized and created by these processes. For this reason, we have selected the most popular standard for BPM, namely, the Business Process Modeling Notation (BPMN 2.0). However, despite its strength representation, this notation does not support the key concepts of BPM4KI (`Sensitive Business Process`,

Table 1: Graphical representation of the different extended elements.

| Concept | Sensitive Business Process | Critical Organizational Activity | Collaborative Activity | Expert | Knowledge | Individual Tacit Knowledge | Collective Tacit Knowledge | Individual Explicit Knowledge | Collective Explicit Knowledge |
|---|---|---|---|---|---|---|---|---|---|
| Notation |  |  |  |  |  |  |  |  |  |

`Collective Action`, `Tacit Knowledge`, `Critical Organizational Activity`, `Expert`, etc.). To remedy at this lack, it should be necessary to extend the BPMN 2.0 notation with several additional concepts. To achieve this goal, we start by defining some specific graphical icons relating to each new proposed concept (see Table 1). Then, in future work, we plan to integrate and implement the extension that we brought to the BPMN specification. In this paper we use these new icons in section 4 to highlight this extension.

## 4 CASE STUDY

We aim to validate the proposed meta-model through its application in the context of the Association of Protection of the Motor-disabled of Sfax-Tunisia (ASHMS). This organization is characterized by highly dynamic, unpredictable, complex and highly intensive knowledge actions. We are particularly interested in the early care of the disabled children with cerebral palsy (CP). An in depth analysis of this care has been made by Turki et al. (2011). In fact, the knowledge used and produced during the treatment of children with CP is very important, heterogeneous and recorded on various scattered sources. One part of this knowledge is embodied in the mind of health professionals. Another part, is preserved in the organizational memory as reports, medical records, data bases, or therapeutic protocols). The created knowledge stems from the interaction of a large number of healthcare professionals from several specialties (such as neonatology, neuro-pediatrics, physical therapy, orthopedics, psychiatry, physiotherapy, speech therapy, and occupational therapy) and located on geographically remote sites. The raised problem concerns on the one hand, the insufficiency and the localization of medical knowledge necessary for decision-making, and on the other hand, the loss of knowledge held by these experts during their scattering or their departure at the end of the treatment. Thus, the ASHMS risks losing the acquired know-how for good and transferring this knowledge to new novices if ever no capitalization action is considered. This organization should focus on only the so called crucial knowledge, that is the most valuable/important knowledge.

Our main objective consists in providing better localization and identification of different types and modalities of pragmatic medical knowledge necessary to the conduct of the medical care process for children with CP. As a matter of fact, this SBP is made up of several sub-processes. It consists of a succession of many actions in the form of medical and paramedical examinations and evaluations. As an example, we mention: Process related to neonatology care, process related to neuro-pediatric care, process related to physiotherapy, etc. These processes require taking into consideration certain medical information contained in the medical records as well as certain medical knowledge (results of para-clinical exams, hospitalization reports, medical records, practice guidelines, etc.).

An enriched graphical representation of the medical care process for children with CP modelled according to BPM4KI meta-model improve the localization of the crucial knowledge mobilized and produced by the critical activities. Moreover, it allows the various stakeholders involved in the medical processes to preserve, share and transfer the tacit knowledge as well as to evaluate the amount of lost knowledge if a person -owner of knowledge- leaves the organization (in order to identify which tacit knowledge in this case should be transformed into explicit knowledge).

In this study, we take into consideration the results of experimentation of the methodology SOPIM proposed by Turki et al. (2014a) for the early care of children with CP. We recall that the proposed multi-criteria methodology was conducted and validated in the ASHMS organization. It aims at evaluating and identifying SBPs (i.e. the processes which can mobilize knowledge on which it is necessary to capitalize) for knowledge localization. Furthermore, the BPM4KI meta-model is based on the core ontology COOP (Turki et al., 2014b) comprising the key concepts inherent to the BP domain which are useful for the characterization and conceptualization of SBPs.

We have opted for the « Process related to the neuropediatric care of a child with CP » to illustrate the contributions of our enriched meta-model. Indeed, this process is very complex in terms of the large number of critical and collaborative activities that make it up, the neuropediatric fields, the large amount of knowledge mobilized, the multitude of knowledge sources, etc. Some of its activities are very dependent on the participants experience, expertise and creativity. We have used the BPMN 2.0 specification (OMG, 2011) in order to enrich the graphical representation of neuro-pediatric care process (modeled according to BPM4KI).

Thus, we have opted for the use of an open source modeling tool namely Aris Express 2.4 (IDS Scheer, 2013). The obtained model is the result of many individual meetings for review and validation with the Neuro-Pediatrician. Figure 2 illustrates an excerpt from the BPMN model of the process related to the neuropediatric care of a child with CP enriched with knowledge dimension.

During our experimentation, we have identified different types of medical knowledge mobilized for each type of activity related to this process. We have distinguished missing or poorly mastered knowledge necessary to resolve critical problems, expertise, unexplainable tacit knowledge and mastered knowledge necessary and relevant to the proper functioning and development of the activity or produced by the activity. We have also identified the different sources of knowledge, their localization, actors who hold the knowledge, the places where they are usable or used, their nature (like experience, basic knowledge, general knowledge), their degree of formalization, their organizational coverage, as well as their quality (perfect or imperfect).

For instance, the knowledge $A_3K_{p1}$ related to « Synthesis assessment of neuro- and psycho-cognitive, neurosensory and praxo-gnosic development of young children at risk and its disorders» is produced by the critical activity $A_3$ « Qualitative and quantitative evaluation of the intellectual functioning » .This knowledge can be stored in the following physical media: the neurological assessment sheet, neuropsychological assessment, the sensitive assessment sheet and the neuro-motor assessment. These assessments are recorded in the personal medical records and in the overall clinical picture of the child. This knowledge is located internally within the Neonatology department in the University Hospital Hedi Chaker. It is captured in the various archives drawers or patients' directories. $A_3K_{p1}$ is of a scientific, technical and measure nature which is related to patients. It represents a collective explicit knowledge, part of which can be represented in the form of an individual explicit knowledge recorded on the care data collection sheet of the Neuro-pediatrician. This knowledge is imperfect (general, incomplete and uncertain). $A_3K_{p1}$ is mobilized by the activity $A_4$ « Establishing an investigation plan ».

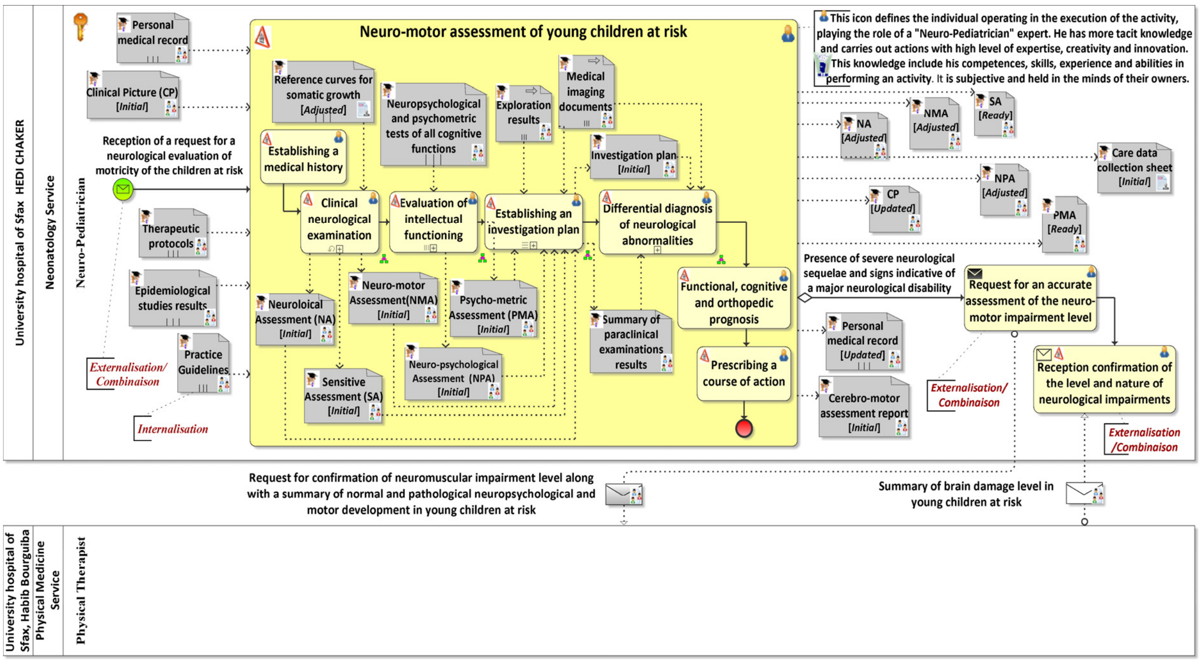



Figure 2: An extract of the graphical representation model of the process of neuropediatric care of a child with CP carried out with ARIS Express 2.4 tool.

The proposed BPM4KI meta-model highlight the following contributions: (i) its suitability for a full and enriched graphical representation of actual SBPs, (ii) validation of its comprehensibility as well as the choice and suitability of the type of modeling by the actors involved in the medical care process for children with CP (who lack experience in BPM), (iii) a better knowledge localization, and (iv) a deeply characterizing of the identified knowledge in order to determine which ones are more crucial.

Furthermore, extending BP models with the knowledge dimension would provide the following benefits: (i) illustrating the knowledge and knowledge sources involved (used, generated, created and/or modified) in the processes and activities, (ii) illustrating the way in which specific knowledge flows among the activities, or how a specific source is used and modified through the activities, and (iii)illustrating transfers of knowledge between sources, and among activities as well as the different opportunities of knowledge conversion.

# 5 CONCLUSIONS AND FUTURE WORK

In this paper, we have focused on the problem of BPs modeling to improve the localization and the identification of crucial knowledge. Therefore, we have proposed a new BPs meta-model, called «BPM4KI», which highlights the key concepts and relationships characterizing SBPs, relying on the core ontology COOP. The aim of this meta-model is to develop a comprehensive and enriched graphical representation of BPs, which integrates all the dimensions of processes modeling: the knowledge, functional, organizational, behavioral, informational and intentional dimension. It has been illustrated by a model of neuropediatric care process of a child with CP through, using the BPMN 2.0 standard.

Various research lines will be performed to complete and deepen the so-called problematic of knowledge identification mobilized by SBPs. Firstly, we consider evaluating the expressiveness of BPM formalisms and their suitability for the representation of SBPs while taking the conceptualization defined by BPM4KI as an evaluation framework. In this context, our objective consists in guiding and justifying the choice of the most suitable formalism to characterize and improve the knowledge localization. Secondly, in order to justify the choice of BPMN 2.0 for SBPs modeling, we intent to adopt the multi-criteria decision making approach (Roy and Bouyssou, 1993). In fact, the proposed BPM4KI should help to construct a coherent family of criteria for the evaluation of the different PBM formalisms. Thirdly, we consider an extension of the BPMN 2.0 for KM. This extension must take into consideration, on the one hand, the knowledge dimension, and on the other hand, integrate the new concepts of BPM4KI (and represents issues relevant at the intersection of KM and BPM). A full and rich representation of BPs (modeled according to BPM4KI) shall allow a better localization and identification of crucial knowledge on which we must capitalize. This extension of BPMN 2.0 will be integrated into a more general framework supporting the SBPs modeling. This framework advocates a MDE approach considering (i) at the CIM level, a specific meta-model, the BPM4KI meta-model for modeling SBPs (ii) at the PIM level, an extension of the BPMN meta-model for visualizing and user validating the modeled SBPs, and finally, (iii) at the PSM level, several meta-models for implementing the different extensions (e.g. XPDL and BPEL meta-models).

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# Confluent Factors, Complexity and Resultant Architectures in Modern Software Engineering

## *A Case of Service Cloud Applications*

Leszek A. Maciaszek[1,2] and Tomasz Skalniak[1]
[1]*Wrocław University of Economics, Komandorska 118/120, 53-345 Wrocław, Poland*
[2]*Macquaire University, Sydney, Australia*
*leszek.maciaszek@ue.wroc.pl, tomasz.skalniak@ue.wroc.pl*

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Abstract: There is a wealth of evidence that contemporary landscape of software development has been resisting the disciplined, rigorous, formally managed, architecture-driven, forward-engineering practices. The whole field of traditional software engineering needs a re-definition alongside the practices widely used in production of modern software systems, in particular service-oriented cloud-based applications. This paper argues that contemporary software engineering must re-focus and re-define its theoretical foundations and base it on acknowledgment that quality software and systems can (and by and large should) be constructed using principles of resultant architectures and roundtrip engineering.

## 1 INTRODUCTION

Software engineering has never matured enough to match theory and practice of traditional engineering disciplines, such as civil engineering. Based on computer science as its foundation, software engineering has struggled to ensure software production with predictable outcomes. The main culprit is the "soft" nature of software and associated demands of users for change and evolution. When combined with the ever growing complexity of application domains that software systems solve, a need for new software engineering has been finding many vocal supporters (e.g. Jacobson and Seidewitz, 2014).

Such a need is additionally propped up by the demands placed by the fact that we live in service economy (Chesbrough and Spohrer, 2006). Almost every modern agricultural or manufacturing product is combined with services, and it is the joint product-service experience that is judged by service requestors, thus truly generating real value for individuals and profit growth for businesses. Interaction and collaboration between actors of a service (suppliers, consumers, and intermediaries) create value-in-context, employment and economic growth. A supplier offers a value proposition that can be realized in a separate process involving requestors and intermediaries. The benefits to all actors define the context of value co-creation.

Service economy exerts new business and pricing models for using information systems without owning them. Such systems are delivered to users over Internet (the cloud) as Software-as-a-Service (SaaS). Services (e-services) in SaaS systems are running software instances, which can be dynamically composed and coordinated to provide executable applications.

The delivery of Service Cloud Applications (SCA) to actors is performed (typically) on Everything-as-a-Service models (Banerjee, 2011), in which software, platform and infrastructure are made available as services paid for according to the usage. This creates ubiquitous marketplace where commercial, social, government, health, education and other services are facilitated, negotiated, coordinated and paid for through marketplace platforms.

We recognize that e-marketplaces for services (such as Airbnb, OpenTable, or BlablaCar) are governed by different business and technology principles than e-marketplaces for products (such as Alibaba, eBay, MarcadoLivre, or Amazon). However, we also recognize that e-service systems narrow the differences between services and products. The dichotomy between these two concepts has been replaced by a service-product continuum (Targowski, 2009). On one hand, software products are servitized; on the other hand, software services are productized (Cusumano, 2008). On one hand, vendors of traditional "boxed" software products use the cloud as a means of servitizing the product (and using it without owning it); on the other hand, productized services (i.e. automation of services, such as movies over Internet) enable "people to participate in a growing number of service-related activities without having to be physically present" (Targowski, 2009, p.57).

The service-product continuum has posed new challenges on the very idea of complexity and change management in a modern-age service enterprise. The responsibilities for complexity and change management have been placed squarely in the hands and minds of the producers and suppliers/vendors of service systems and applications (but much of the risk is still endured by the enterprises and consumers receiving/buying the services).

The established disciplines of software engineering (e.g. Maciaszek and Liong, 2005) and systems analysis and design (e.g. Maciaszek, 2007) have advocated architecture-driven forward-engineering processes. Modern practices challenge the merits and economics of the architecture-first approach to software engineering (Booch 2007). They also challenge the rigid top-down development epitomized in three consecutive phases of systems analysis, design and implementation. They do not, however, challenge the traditional architectural design role of managing system complexity expressed in terms of dependencies between system elements.

The paper is organized as follows. The next Section considers service cloud applications as a significant disruptive technology and it explains the main confluent factors that shape the future of modern software engineering.

Section 3 reiterates the fact that complexity of modern software systems lies in the interactions and dependencies between software elements, which – by the object-oriented paradigm – are internally relatively simple (or at least they should be simple). This section classifies dependencies and explains how SoaML can be used to model SCA software structures.

Section 4 discusses the idea of resultant architecture as a replacement for the architecture-first paradigm. The section proposes a meta-architecture for service cloud applications and it positions the roundtrip engineering as a modus operandi of modern software engineering.

The final Section contains concluding remarks. It emphasizes the necessity of designing for change as opposed to just programming for change. It makes also a clear distinction between emergent and resultant architectures.

## 2 CONFLUENT FACTORS

The contemporary practice of development of service-oriented cloud-based web and mobile applications changes the pressure points and creates new expectations with regard to modern software engineering. Figure 1 is a Venn diagram that names the main confluent factors that bring about a need for redefinition of software engineering as a discipline. The overlapping between factors is significant. It emphasizes that the factors frequently come together in various combinations.

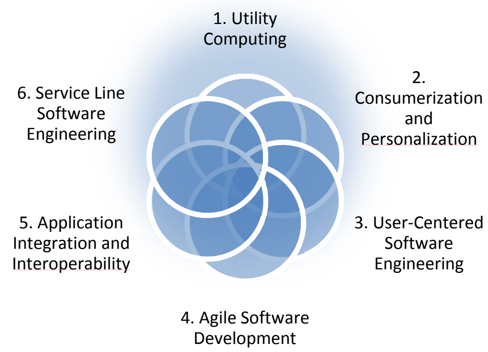


Figure 1: Confluent factors of modern software engineering.

The SCA are delivered over Internet as a kind of utility/commodity similar to energy, water, gas, telephony, and alike. They are a fact of live and are omnipresent - they are available on mobile devices at any time and any place and they can adjust to the context of use (including the current user needs, the geographical position, the temporal information, the weather conditions, the signals from the Internet of Things (IoT) sensors and actuators, etc.). Utility computing is the first confluent factor of modern software engineering.

Service innovation is consumer-focused. Consumer market, as the primary driver of CSA innovation, challenges the way companies innovate and evolve with IT. The innovation ideas need to tap into the phenomenon of consumerization and personalization as the tendency for new IT solutions to emphasize consumer-focused service provision and to emerge first in the personal consumer market and then spread into business and government organizations. Consumerization and personalization open up an opportunity for new business models and ways of value creation, and it is the second confluent factor of modern software engineering.

By centering on consumerization, personalization, and collaborative context-dependent value creation, the modern software engineering shifts decisively towards user-centered engineering (Richter and Fluckinger, 2014; Ko, et al., 2011) and what Brenner et al. (2014) call user, use & utility research (or 3U research, to use another parlance). Although software engineering has always been recognizing significance of user's acceptance of a solution, the development of SCA systems not just recognizes, but focusses on users by emphasizing the software quality of usability (ISO, 2011) and delivery of a great User eXperience (UX) instead of delivery of software product. User-centered software engineering is the third confluent factor of modern software engineering.

The user-centered software engineering synchronizes nicely with the agile software development that dominates contemporary software engineering practice (Moran, 2015). The agile development methods, such as Scrum, are responsible for a real shift from the architecture-first approach - if not in theory, then certainly in practice. The agile software development is the fourth confluent factor of modern software engineering.

Although the agile methods are called development methods, in reality a great majority of software projects are undertakings in value-added software integration and interoperability (Maciaszek, 2008a). Most new software applications must integrate and interoperate with existing applications and databases, thus making them value-added applications. The whole technology of web service orchestration is about integration and interoperability of SCA-s. Application integration and interoperability is the fifth confluent factor of modern software engineering.

The owner/supplier of a SCA platform sets up instances for the SCA users. Customization and variability of instances is based on the technology of multi-tenancy and uses the emerging principles of Service Line Engineering (SLE) (Mohabbati et al., 2013; Walraven et al., 2014)). Service Line Software Engineering is the sixth confluent factor of modern software engineering.

# 3 COMPLEXITY IN-THE-WIRES

The times when software complexity could be measured in lines of code or function points are long gone. Since the object-oriented paradigm has replaced the structured programming reminiscent of Cobol systems, the monolithic size of a program ceased to be an indication of software complexity.

Complexity of modern modularized systems comes from the relations between the modules (be them objects, classes, components, packages, services). Complexity is in-the-wires between the modules, not in the modules themselves.

In our past research, we have extensively discussed the complexity in-the-wires principles for large on-premise enterprise information systems (e.g. Maciaszek and Liong, 2005; Maciaszek, 2007). We have demonstrated that complexity minimization is synonymous with the minimization of the inter-module dependencies, where dependency is "a relationship that signifies that a single or a set of model elements requires other model elements for their specification or implementation. This means that the complete semantics of the depending elements is either semantically or structurally dependent on the definition of the supplier element(s)."(OMG, 2009)

It is important that complexity management revolves around software metrics that monitor and measure dependencies in the engineered code. The Design/Dependency Structure Matrix (DSM) (e.g. Eppinger and Browning, 2012) is an excellent method for visualizing, measuring and analyzing dependency relationships in software. Today many tools exist that support the DSM method, e.g. Structure101 (Structure, 2015).

In Maciaszek (2008b) and elsewhere we have discussed the ways of using DSM for the analysis and comparison of software complexity in large systems. We have applied the DSM analysis to the PCBMER meta-architecture consisting of six hierarchical-ordered software layers: Presentation, Controller, Bean, Mediator, Entity, Resource (e.g. Maciaszek, 2007).

When using DSM or other software metrics to calculate dependencies, it is important to consider various categories of dependencies and their relative importance (weight) in measuring complexity and adaptability. At a relatively high level of abstraction pertaining to complexity analysis of traditional enterprise applications, four categories need to be considered: message dependencies, event dependencies, inheritance dependencies and interface dependencies (Maciaszek and Liong, 2005).

Complexity of modern service-oriented cloud-based applications can also be discussed based on these four categories of dependencies, but better classifications seem to be those that put services at the forefront of the discourse. One possibility is to consider just three categories of dependencies: services, references, and properties (only services are discussed in any depth in this paper).

Since "a service is value delivered to another through a well-defined interface" (SoaML, 2015, p.7), we need to concentrate on interface dependencies when engineering SCA-s. To this aim, we can adopt the SoaML (Service oriented architecture Modeling Language) standard (SoaML, 2015). The standard distinguishes three ways of service interaction: a simple interface, a service interface, and a service contract.

A simple interface is a UML-style interface as supported by popular object-oriented languages, such as Java, and web services called via RPC (Remote Procedure Call). Simple interfaces are uni-directional – the consumer calls a provider's service and the provider does not callback the consumer and may not even know it.

A service interface involves bi-directional communication between provider and consumer. "The service interface may also specify the choreography of the service - what data, assets and obligations are sent between the provider and consumer and in what order. ... The consumer must adhere to the provider's service interface, but there may not be any prior agreement between the provider and consumer of a service." (SoaML, 2015, pp.8-9).

A service contract defines how participants (providers, consumers, and other roles) work together to exchange value. To this aim, service specifications are defined in a service contract. The contract determines the participants, the interfaces, choreography, and any other terms and conditions for the enactment of the service. Service contracts are therefore encapsulation (implementation handling) mechanisms.

Service interactions via interfaces and contracts are principle communication means between software architectural layers. The layers can be represented as UML collaborations. They can contain the SoaML service capabilities, which "identify or specify a cohesive set of functions or resources that a service provided by one or more participants might offer." (SoaML, 2015, p.29).

Capabilities may be related to show intra-layer dependencies. They can aslo be used to visualize and define intra-layer dependencies, in particular they can specify the behavior and structure of interfaces (realized by the capability, which in turn is realized by a service participant). Capabilities can be nested/combined to form larger capabilities.

Capabilities can be related by 'usage' relationships. An 'expose' relationship can be used to indicate what capabilities (required or provided by a participant) should be exposed through a service interface. However, the operations and properties of a service interface may differ from operations and properties of a capability it exposes. "It is possible that services supported by capabilities could be refactored to address commonality and variability across a number of exposed capabilities" (SoaML, 2015, p.47).

The UML interface realization can be used to denote service interfaces that a capability 'realizes' (implements). As with the 'expose' relationship, the operations and properties of a service interface and a capability may differ.

SoaML also defines the notion of a service channel as a communication path between consumer requests and provider services. The service channels between and within the architectural layers determine the complexity and adaptability of a service system.

## 4 RESULTANT ARCHITECTURE

In our past research we have argued that a valid answer to the software complexity and adaptability is the architecture-first design, i.e. that the architecture should be designed into the system. However, we have always recognized that the proactive forward-engineering architecture-first approach requires a parallel contribution from a reactive reverse-engineering approach (Maciaszek, 2005). In other words, we have recognized that the architecture should result from roundtrip engineering. The concept of a resultant architecture, used in the titles of this paper and this section, is a consequence of of the above interpretation of roundtrip engineering.

The primary purpose of an architecture is to minimize complexity of expected outcome and to lead to a solution that is adaptive, i.e. understandable, maintainable, and extendable. Software engineering and management has struggled to properly address systems complexity and adaptability. The reason is twofold: deficient architectural design and/or nonconformance of software implementation to the architectural design.

The paradigm shift to SCA-s has introduced new threats and opportunities with regard to complexity management and delivery of adaptive solutions. On one hand, the SCA-s assume dynamic composition of services and tenant variability and, therefore, they emphasize implementation over architecture (and over project management at large). On the other hand, the SCA-s are built on the technologies that, by their very nature, support adaptability. The concepts such as loose coupling, abstraction, orchestration, implementation neutrality, configurability, discoverability, statelessness, immediate access, etc. are exactly the ideas of adaptable architectural design.

Figure 2 represents our meta-architecture (i.e. an architectural reference model) for SCA-s, called Meta-SCA. The model retains the conceptual thrust of the PCBMER meta-architecture and it provides roundtrip engineering perspective on our recently defined STCBMER (Smart Client, Template, Controller, Bean, Mediator, Entity, Resource) meta-architecture (e.g. Maciaszek et al., 2015).

The Meta-SCA model recognizes and even emphasizes the fact that SCA engineering activities are facilitated by software toolkits and frameworks. Toolkits enable code reuse. They support programmers in writing the real code – the main body of the program. Frameworks enable design reuse. They provide to programmers a skeleton of the program and inform programmers which code to write, so that the framework can call it.

Toolkits and frameworks deliver reusability at the level of software implementation, but they need to be chosen to facilitate the forward engineering objective of minimizing complexity and maximizing adaptability. Frameworks need to facilitate implementation of the meta-architecture; toolkits need to facilitate implementation of patterns and principles. In the reality of SCA-s, toolkits and frameworks can be encapsulated within the technology of Platform-as-a-Service (PaaS).

The Meta-SCA model defines four hierarchical layers for the application code placed on top of a Data Storage layer. The four layers are called Client Front-end, Client Back-end, Business Service and Data Access. They are modeled as SoaML collaborations and stereotyped as <<ServicesArchitecture>>.

Each layer contains single SoaML <<Participant>> realizing specific capabilities. Participant at a higher layer requests services implemented in participants in lower layers. This is represented on the model by the UML notation of required and provided interfaces (so called lollypop notation). It also indicates a top-down single directional interface dependency between layers.

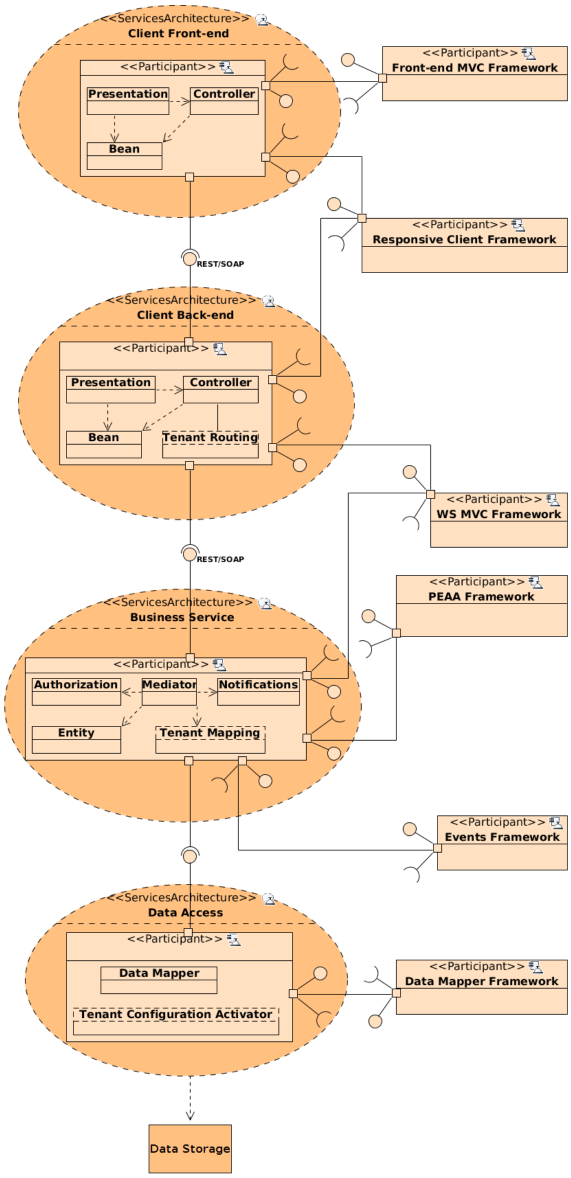


Figure 2: Meta-architecture for service cloud applications (Meta-SCA).

The service discovery can be realized through WSDL (Web Services Description Language). The service binding can be realized through SOAP (Simple Object Access Protocol), but even better degree of software adaptiveness can be achieved if the statelessness of the system is not an issue. If it is not, then the REST (Representational State Transfer) architecture might be more desirable than the SOAP.

In parallel to the layers, the Meta-SCA model defines other participants, which are third-party frameworks and toolkits supporting the system's implementation. Each framework is understood as a service offering a special “framework interface” that is needed by some of the components of the proposed meta-architecture.

Relations between frameworks and layer participants are defined as bi-directional service interfaces. This is because to use a framework you to have to deliver to it a code, which satisfies strict conditions defined by the framework. Also, the frameworks have to offer a given set of functionalities to the layer participants.

Some frameworks in Meta-SCA – Responsive Client Framework and SW MVC Framework – are needed and used by two different layers. In such a case, each framework has its own framework instance (this way the Meta-SCA does not introduce to the model disallowed dependencies).

Each layer participant has various components inside. The dependencies between those components can be organized in various ways – according to different need of a specific environment, technologies and project as well as chosen frameworks (which support the implementation). The organization of those dependencies follows the guidelines and propositions consistent with and based on the PCBMER and STCBMER studies.

The Client Front-end and Client Back-end layers form an abstract application layer, while the Business Service and Data Access layers together form an abstract business layer (e.g. Maciaszek et al., 2015).

The Front-end MVC framework is a JavaScript framework needed to implement complex, off-line, widget-based asynchronous web applications. The Responsive Client Framework is a presentation framework supporting implementation of Responsive Web applications.

The Web Services MVC Framework is a server-side framework, which offers building the web services communication as well as layering the code into separate parts based on different variants of the MVC pattern. These types of frameworks are often called just web frameworks.

The PEAA Framework means a framework containing different, needed implementations of the patterns from the Catalog of Patterns of Enterprise Application Architecture by Martin Fowler (2013).

The Events Framework refers to frameworks and toolkits offering project-specific event-based implementations. This includes authorization tools and notification schemes (e.g. SMS notifications), but also any other event-driven mechanisms allowing interoperability with cyber-physical monitoring systems (IoT sensors and actuators) and integration with enterprise, government and social networking systems.

The Data Mapper Framework is a type of framework, which offers connecting to a database or other data stores, mapping of database entities to programming objects, transaction management, etc.

Table 1 presents examples of Meta-SCA frameworks and toolkits.

Table 1: Examples of Meta-SCA frameworks.

| Framework | Examples |
|---|---|
| Front-end MVC Framework | Angular.js, Backbone.js, Knockout.js |
| Responsive Client Framework | Bootstrap, Foundation |
| WS MVC Framework | Django, Pyramid, Rails, Spring MVC, ASP .NET, Symfony |
| PEAA Framework | Spring, .NET, Django REST Framework |
| Events Framework | JMS (Java Message Service), Activiti, Kinoma |
| Data Mapper Framework | Hibernate, SQL-Alchemy |

Some of the meta-architecture components (Tenant Routing, Tenant Mapping, Tenant Configuration Activator] are placed in the diagram to emphasize that modern tenant-oriented systems often need to have tenant-specific code in different layers. In addition, this special code has to cooperate with the frameworks used in a specific project. As a result there is a need of having the code organized in independent modules that can be easily used when needed.

There are several ways of building the tenant-based systems. Separation of data and functionalities can be implemented on different layers of the system (also the databases often are playing a role in it). That is why the proposed meta-architecture has different tenant-specific components placed in different layers. In reality not all of them might be needed – based on the chosen design patterns, different layers might or might not need the tenant-specific code.

Concrete instances of architectures derived from the Meta-SCA in the roundtrip engineering process need to conform to the additional rules and principles over and above the layering shown in Figure 2. Because of the space limitations of this paper we cannot describe them in any details. Nevertheless most of the twelve principles defined for the STCBMER meta-architecture (Maciaszek et al., 2015) remain relevant for the Meta-SCA.

Three most fundamental principles from the PCBMER and STCBMER - DDP (downward dependency principle), UNP (upward notification principle) and CEP (cycle elimination principle) - fully apply to the Meta-SCA. This means, that message dependencies are only allowed in downward communication between layers and the upward communication requires event notifications from lower layers, possibly combined with the use of interface inheritance. Implementation inheritance is disallowed between layers; it is restricted to intra-layer implementations. Cycles of message communications (method invocations) are disallowed between layers, inside layers, and for any granularities of objects (classes, components, packages, web services). Cycles need to be eliminated using well-known software engineering rules, exhaustively explained for example in Maciaszek and Liong (2005).

In reality – when programmers start to code – it is very hard to stick to the abstract meta-architecture without breaking some of its principles and assumptions. This is because of different patterns chosen to base the frameworks on and because of various technologies used by the frameworks.

Since the frameworks in modern software engineering are more and more becoming the backbones of the software solution, it is very important to choose the right ones for implementing a concrete instance of the architecture so that it fully conforms to the abstract meta-architecture. There are two ways of how to do this. The first is by choosing the frameworks which are compatible with the meta-architecture. The second is by choosing the frameworks which are modular and flexible enough to set them up in a way that is satisfying the meta-architecture. Nowadays many frameworks have sufficient modularity and flexibility so that the programmers can easily replace predefined framework's components with other implementations – written by themselves or by third-party organizations.

The conformance of the project's resultant architecture to the meta-architecture and its principles should be evaluated by an in-depth analysis of dependencies. This must involve some reverse-engineering of code to establish factual dependencies to compare them against the allowed dependencies of the meta-architecture. The DSM method briefly discussed in Section 3 provides an excellent vehicle for dependency analysis and calculation of dependency metrics.

Unfortunately measuring the dependencies in a project built with the help of a number of frameworks and toolkits is a difficult task. It constitutes a new and important research challenge. We intend to focus on this problem in our future work and to measure the impact of contemporary frameworks and toolkits on architectural design of SCA-s from the viewpoint of software complexity and adaptiveness.

# 5 CONCLUDING DISCUSSION

Traditional software development lifecycles assume architecture-first design (Booch, 2007; Maciaszek, 2007). However, the confluent factors of modern software engineering have led to practices where software architecture evolves in parallel with software construction. As noted by Jacobson and Seidewitz (2014), "...agile development have made it possible to create high-quality software systems of significant size using a craft approach - negating a major impetus for all the up-front activities of software engineering" (p.50).

Moreover, modern multi-tenant SaaS applications (Walraven et al., 2014) demand the built-in capability of dynamic software adaptation (Kakoutsis et al., 2010). This in turn requires inventing new architectural styles that respond to and embrace the dynamic runtime software adaptability (not addressed in this paper, but refer e.g. Kakoutsis et al., 2010).

Roundtrip engineering activities that aim at resultant architectures for SCA-s are based on and driven by various reuse strategies (e.g. Maciaszek, 2007). The forward engineering activities are driven by an assumed meta-architecture. Associated with the meta-architecture are matching architectural patterns and architectural principles. A meta-architecture delivers reusability at the level of a solution idea. Patterns and principles deliver reusability at the level of software design.

The reverse engineering activities aim at software architecture recovery (e.g. Solms, 2015) and at measurably validating the conformance of a system's resultant architecture to the meta-architecture (Maciaszek, 2008b). An ultimate objective is a SCA that minimizes complexity and maximizes adaptability.

Information systems in general, and service cloud applications in particular, need to be designed for change. They need to be adaptive. Ideally, they need to be self-adaptive, but such an aim is unreachable as yet in practical software engineering (Maciaszek, 2012).

The confluent factors of modern software engineering reflect the necessity of designing for change. Unfortunately, this is not sufficiently reflected in contemporary practice of software engineering. Current practice is full of ideas, methods and tools to facilitate development/programming for change, but lacks systematic and rigorous approach to designing for change.

The development/programming for change is exemplified, for example, by the growing popularity of DevOps, which is an approach to merging development and operations (Huttermann, 2012). Another example, on the level of user interface and web programming, are approaches known as responsive development, progressive enhancement, graceful degradation (Overfield et al., 2013).

The design for change must revolve around the software architecture, which sets a fundamental structural organization for a software system. Such an organization must determine hierarchical layers of software elements (components, objects, services) ensuring separation of concerns and resulting in a tractable/adaptive complexity of the solution.

There seem to be three approaches to considering software architecture in software engineering projects. The architecture:

1. can be designed into the system,
2. can emerge from the implementation,
3. can result from roundtrip engineering

The first approach is synonymous with the architecture-first approach. It is a commendable approach, but increasingly impractical in the fast-paced world demanding immediate software solutions.

The second and third approach can be best understood by reference to complexity theory (e.g. Agazzi, 2002). Since complexity entails existence of relations/dependencies between elements, then - by opposition - simplicity (something that is analytically simple) entails no internal relations.

Further, the complexity theory distinguishes between emergence and resultance. We speak of emergence when a complex structure emerges from the properties of the “analytic simples” in a way that is not completely understandable and explainable. In this sense, software architecture can emerge in a bottom-up fashion from the implementation of software elements.

By contrast, we speak of resultance when a complex structure results from the properties of the analytic simples by the guidance of the relations between software elements. This means that a meta-architecture exists prior to the implementation and it guides software engineers in designing concrete system architecture (an instance of meta-architecture) in parallel with software implementation. This is a roundtrip engineering effort leading to, what we call, a resultant architecture.

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# Enterprise Methods Management Using Semantic Web Technologies

Peter Rosina and Bernhard Bauer
*Software Methodologies for Distributed Systems, Institute of Computer Science*
*University of Augsburg, Universitätsstr. 6a, 86135 Augsburg, Germany*
*firstname.lastname@ds-lab.org*

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Abstract: Due to today's product complexity and variety and a shortening of development cycles, for instance, in the automotive domain, a conventional knowledge representation and management of the various design methods is not reasonable anymore. By acquiring the relevant domain and business knowledge from IT applications, documents and experts and creating ontologies, business rules and queries thereof, domain experts can manage this knowledge independently and thus react faster to the ever-changing development process.
Using Semantic Web technologies, we created a methods ontology that enables domain experts to analyze and compare method meta knowledge, e.g., about physical and virtual CAx methods. Furthermore, this particular domain and business knowledge features interdependencies with the remaining enterprise knowledge, including business processes, organizational aspects and the IT architecture. Therefore, we show concepts for the integration of this method meta knowledge into an enterprise architecture.

## 1 INTRODUCTION

The task of R&D divisions in the automotive domain comprises forming ideas for new products, i.e., the product planning, and the design in different stages until it is ready for the start of production in the production division. Naturally, a multitude of different disciplines and departments, for instance, physical crash tests and virtual simulations, have to collaborate, cooperate and interact during this process which entails the application of a large number of various technologies and working methods (*cf.* section 3), for instance, Computer Aided x (CAx) methods. CAx comprises the Computer Aided Design (CAD) that provides approaches for the virtual design and verification of products and their geometry. Further involved disciplines are the Computer Aided Engineering (CAE) and Testing (CAT); the former provides methodologies for simulating the behavior of a car and its functions, e.g., Finite Element Analysis (FEA) for crash simulation; the latter for performing physical tests, e.g., vehicle management, job, and testing control, and test result analysis. The involved tools and methods range from mechanical test beds, through Hardware in the Loop (HiL) to Digital Mock-Ups and other pure software applications.

Our goal is to create an integrated model that depicts this domain of methods, technologies and tools in order to support stakeholders in their daily work. Nowadays, a method selection for a defined purpose, an analysis of the entirety of methods in a company and the method monitoring are mainly manual tasks, ever and anon assisted by basic IT documents, like spreadsheets. Formalizing this knowledge allow the involved roles to analyze methods along the product development process, for instance, for finding virtual replacements for physical tests. This meta model and the resulting ontology are introduced and explained in section 4.

We realized our meta model, resulting ontology and a prototypical application, following the ONTORULE approach (de Sainte Marie et al., 2011). Using Semantic Web technologies (*cf.* section 2.1) bears many advantages: on the one hand, it enables a clear separation of domain and business knowledge, that can be extended and modified by domain and business experts. On the other hand, this knowledge can be implemented and managed independently from the applications that process it.

Finally, in order to benefit mutually from the additional knowledge available in an enterprise, we illustrate how to combine our method meta model with an enterprise architecture (EA) meta model in section 5. The basics about EA are introduced earlier in section 2.2. In section 6, we shortly present a prototypical demonstrator showcasing the method meta ontology and its application. Furthermore, we discuss the opportunities that emerge by combining method and EA meta models. The paper is then summarized in the final section 7.

# 2 BASICS

## 2.1 Semantic Web Technologies

Bringing the Semantic Web to fruition is an collaborative endeavor of various research groups, industrial partners and organizations pursuing the common goal to enrich the WWW with semantic data, thus transforming the web from an un- or semi-structured document based technology to a knowledge-centered one. (Berners-Lee et al., 2001) developed the vision of the Semantic Web in order to make the web's meaning machine-readable and -interpretable and hence integrate heterogeneous data and infer new information from existing knowledge bases (KBs) automatically.

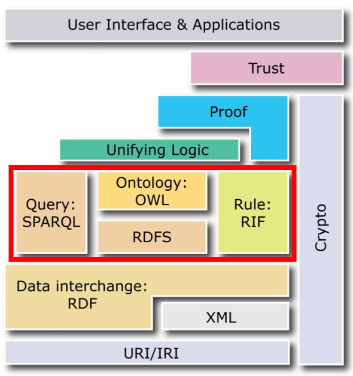


Figure 1: Semantic Web layercake (after (W3C, 2007)).

The prominent Semantic Web Stack in Figure 1 depicts the architecture of the Semantic Web, which is still in development and continuously improved. The lower layers provide the technological basement for the subsequent upper layers. The highlighted layers' containing formats, i.e., RDFS, OWL (W3C OWL Working Group, 2012), RIF (Kifer and Boley, 2013) and SPARQL (Harris and Seaborne, 2013), serve as our technological foundation. This paper represents an excerpt of our ongoing work, though. Therefore, we focus on modeling ontologies with the knowledge representation language OWL. OWL ontologies separate a terminological box (TBox), representing the ontological concepts, and the modeled individuals in the assertional box (ABox). Moreover, we do not necessarily apply these technologies for the WWW, but for the enhancement and realization of enterprise domain models and their applications.

## 2.2 Enterprise Architecture Management

Many enterprises' IT landscapes have reached a degree of complexity that is only hard to understand and manage (Hanschke, 2013). Additionally, the IT needs to be aligned to business services and processes for an optimal and efficient support. For this purpose, many organizations have established an EA Management (EAM), motivated by the circumstance, that business is changing faster and faster due to shorter development cycles, adaptation and reorientation of business models and an overall need for improving the business and IT alignment.

EAM helps companies to reduce costs for maintenance and developments when confronted with an increasing number of systems by analyzing "areas of common activity within or between organizations, where information and other resources are exchanged to guide future states from an integrated viewpoint of strategy, business and technology" (EABOK Consortium, 2015).

Success factors are a goal-oriented adaption towards changing market and boundary conditions, the detection of redundancies and the definition, determination and an ongoing assessment of the various EAM Key Performance Indicators (KPIs) (Auer et al., 2011). "Above all, [EA] recognizes that the information assets of an enterprise are always in flux, and that this flux is the steady state" (Wood, 2010).

An EA's centerpiece is its meta model. It represents the diverse required aspects of a company's IT and business structures. These are, for instance, elements such as processes, services, organizational structures, data, applications and technologies. They are connected and organized via various relations and clusters which form the EA. The IT architecture can be further subdivided into architectures covering software and technology.

Every company is unique, with diverging requirements, goals and focus areas. For this reason, a suitable, customized meta model is more important when introducing an EAM in a company than a tool which comes along with an inflexible standard meta model.

An EA Framework (EAF) describes a methodology for developing an EA and its use during operation. It points out the relevant aspects and focuses that an enterprise should consider when creating information systems. Some examples for EAFs are *The Open Group Architecture Framework (TOGAF)* (The Open Group, 2011), *ISO 19439:2006* or the *US Federal EAF*, to name just a few (Matthes, 2011).

TOGAF, together with ArchiMate (The Open Group, 2013), serves as the foundation for our EA meta model. It provides a methodology for the design, planning, development, implementation and maintenance of an EA (The Open Group, 2011). It does not feature a specific model the companies can use, but offers meta models and guidelines that should be applied as seen fit and as required.

TOGAF partitions an EA into four main architecture tiers: the *Business*, *Data*, *Application* and *Technology architecture*. The *Data* and *Application Architecture* are part of the *Information Systems Architecture*. In this paper, we mainly focus on the business level and its relations to the information systems, for instance by dealing with business strategy, processes, organizational structure and business capabilities and the applications relevant for the execution of the business processes.

The meta model along with suitable tools and an EAF allows the enterprise to document and monitor the business and IT architecture in a holistic way which enables the architects and managers to react faster to occurring changes in an agile enterprise. Furthermore, modeling the business and IT architecture leads to an increased transparency which in return drives the use of a common vocabulary in the company and hence reduces misunderstandings. Other benefits are the advancement of standardization, an improvement and assurance of quality, a reduction of IT costs and consequently an improved coping with risks.

Generally speaking, the above listed advantages should provide a fillip for any organization. However, introducing an EAM is especially worthwhile for big enterprises. Such an enterprise can even be an "extended enterprise", that "nowadays frequently includes partners, suppliers and customers", as well as internal business units (The Open Group, 2011). On the one hand, small organizations shun the undertaking, because it is wedded to a lot of effort – time- and resource-wise. On the other hand, a big enterprise, with an historically evolved IT landscape and complex business processes, will see the most benefits from such an endeavor.

# 3 RELATED WORK

Our model has been mostly influenced by the domain of CAx methods, in particular, our primary goal was to model and analyze CAD, CAE and CAT methods. However, we soon discovered, that a method meta model covering not only CAx, but a much bigger selection of working and design methods is of even greater value.

Depending on the department or company, even of the same domain, e.g., automotive engineering, a method can be synonymous to a *tool*, a *process*, a kind of technique for solving or analyzing problems or a combination thereof. In software engineering, the term is usually associated with a *procedure*, i.e., a segment of a framework, of a software development methodology, e.g., the waterfall model or an agile development framework.

This ambiguity impedes the communication between people with a different background and leads to unnecessary misunderstandings and coordination phases. Thus, a standardization of the semantics would be worthwhile.

Methods have been used for decades in the domain of Design Theory and Methodology – an approach for the methodical development of products by using "effective methods to support particular development steps and [guide users] to efficiently solve development tasks" (Birkhofer, 2011). However, according to (Pahl et al., 2007), the industry only reluctantly adapts design methodological models and methods.

By definition, a method is a systematic *procedure* for the *attainment* of something (Oxford Dictionaries, 2015) (Merriam-Webster.com, 2015), for instance, for the attainment of [scientific] insights or practical results (Duden, 2015).

Because our running example originates from the automotive domain, we also incorporate domain specific method definitions and are inspired by existing method frameworks, e.g., from systems engineering and method development (*cf.* (Weigt, 2008)).

A method consists of one or many *procedures* that are interconnected by logical rules (*alternative*, *predecessor*, *successor*, etc.) (Hesse et al., 1992) (Chroust, 1992). Methods are prescriptive which means they are perceived as some kind of instruction or plan (Lindemann, 2009) and they cannot be applied universally, but *every method has a particular stage in the development process* where its execution offers the best outcome (*cf.* (Meerkamm, 2011)). More precise, methods are used in development processes for supporting a systematic and *aimed execution of tasks* (Lindemann, 2009). Additionally, plans and methods must be adapted to the specific situation they are used in which means that a method can produce entirely different results and qualities depending on its environment. Among others, this includes the user itself. They have different knowledge, experiences, skills, tendencies and their form on the day is variable as well. Furthermore, the quality *depends on the tools* that are used to execute a method, the type of *business process* a method supports and of course the *quality of its input parameters*.

According to (Müller, 1990), methodical support should be coordinated with its respective boundary conditions. In particular, it should be differentiated between the boundary conditions of the *organizational and operational layers* (Weigt, 2008). Boundary conditions of the organizational kind include *role descriptions*, the mapping to *business processes*, *organizational structures* etc. The operational layer comprises information about the *tools* used to conduct the method, its *qualities*, *time consumption* and *costs*.

(Cronholm and Ågerfalk, 1999) define the relations between the different method concepts in even more detail by defining the relations between them: methods can be vertically linked, thus creating *method chains* – the outcome of the previous method is the input for the next method. A *method alliance* on the other hand, is a horizontal composition of methods, i.e., a family of similar, alternative methods. Another important concept is the *perspective*, i.e., how methods are perceived and what level of detail and focus is presented to the user.

Another significant aspect for the definition of methods, more precise for the framework of methods (Cronholm and Ågerfalk, 1999), is the *methods' structure*. According to (Lindemann, 2009), it is not a simple task to clearly classify methods and put them in some hierarchical structure. A kind of network or graph, e.g., an ontology, is best suited for this task, because single methods and their partial procedures can be applied in other methods as modules as well which "supports a flexible selection, adaption and combination of methods" (Lindemann, 2009).

A method typically consists of the five bullet points listed below (Lindemann, 2009):

**Purpose / Goal:** A task in the development process which is supported by the method.

**Situation:** The scope, problem descriptions and boundary conditions the method is usually appropriate for.

**Effect:** Effects and side effects, that are attained by executing the method, i.e., the method's output.

**Procedure:** The performed steps when executing the method.

**Tools:** Form sheets, check lists, software, test beds, etc.

Braun and Lindemann have analyzed the selection, adaption and application of product development methods for the impersonal transfer of method know-how, which resulted in the Munich Model of Methods (MMM) (Braun and Lindemann, 2003). It acts as the foundation for a method model which consists of method building blocks that are linked by method attributes. Furthermore, the model supports the implementation of *superior tasks* and *resources* and *support* (*cf.* Figure 2) can be related to a procedure.

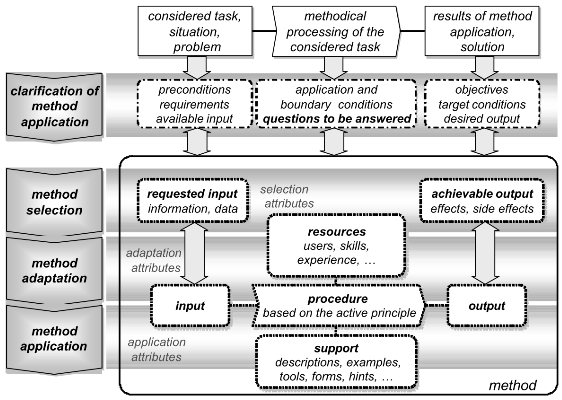


Figure 2: The *Munich Model of Methods* (Braun and Lindemann, 2003; Lindemann, 2009).

The MMM comprises various steps for applying a method.

The diagram depicted in Figure 2 is horizontally split into four phases. It juxtapositions method attributes and the method implementation during the *process action*. The first lane deals with the clarification of the method's use case scenario. The following lanes represent the method selection, its customization and its application.

Vertically, the model is divided into different process building blocks, i.e., the requirements phase, boundary conditions and concerns concerning the method application and of course the method's *goal* and *output* in the third vertical lane (Braun, 2005).

The single phases are supported by various *tools*.

The majority of the depicted blocks are also covered by our method ontology, because the entities concerning a method definition, like *input*, *output*, *goal*, *procedure* etc., necessarily have to be implemented in a model when dealing with design methods.

# 4 METHOD META MODEL

Our method meta model allows to semantically express the relations of tools and methods in combination with their tasks and processes on an abstract layer but also offers the possibility to describe concrete methods and their boundary conditions, e.g., the available time or budget.

Furthermore, our model allows to annotate the quality of their interactions, based on a maturity scale. To achieve a common understanding, we created a method meta model that has been implemented with OWL later on, by working closely together with industrial partners and regarding state-of-the-art definitions and models. Further necessary knowledge that has been derived from our gathered requirements, i.e., to answer requested information, has been implemented in the form of queries and rules. These are not presented in this paper, though.

## 4.1 Method Ontology

The resulting method ontology's core structure is depicted in Figure 3. We use the attribute "core", because this ontology can and should be extended with further ontologies. The ellipses in the figure represent ontology classes and the directed edges stand for properties, whereas their beginning is the property's domain and the arrowhead represents its range. Multiple properties between the same classes are consolidated into a single edge for a better overview; they are separated by commas between the edges' labels, though.

When talking about a method's maturity, quality or other concerns, we have to take into account, that a method can be applied at several points in a company's processes. Usually, the quality of data or resources rises over time, when the product itself is becoming more and more ready for series production. Assuming that we have a method $A$ in our method KB which can be applied at two different points of time in the product development process, it is conceivable that this method is conducted using input resources of a differing quality. Vice versa, the method's application is resulting in similar, but of differing quality, resources which have to be available at a specific point of time in the process, e.g., a milestone. Nonetheless, it is still the same method, supported by the same tools and performed by similar procedures. Independently, a method can also be applied with the same, or at least the same quality and kind of, resources multiple times in a process. In order to distinguish between these (concrete) instances of a method and the general (abstract) method they have been derived from, we have introduced the concepts `Concrete Method` and `Abstract Method`. An abstract method $M_a$ is a concept that defines a class of process-independent methods. A concrete method $M_c$ is a concept that defines a class of methods, linked to a process action and derived from an abstract method $M_a$.

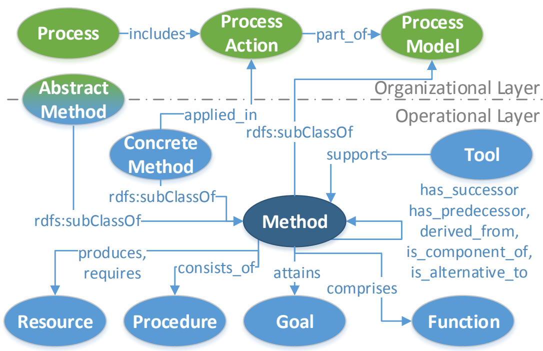


Figure 3: Structure of the core method ontology.

In Figure 3, both, the `Abstract Method` and the `Concrete Method`, are specializations of the concept `Method`. The `Method` is a specialized type of a `Process model`. Methods offer suggestions for specific tasks' sequences and the fashion on how these tasks are to be conducted (Lindemann, 2009). Following the example of (Eisenbarth, 2013), a `Process Action` is equivalent to a task and hence, a `Concrete Method` is `applied_in` a specific task that is again related to a `Process`. Because both method types inherit the object properties of `Method`, we can model interrelationships between `Concrete Methods` and respectively `Abstract Methods`, and can also state that some arbitrary `Concrete Method` is `derived_from` a specific `Abstract Method`. The remaining object properties allow us to model classes of methods such as method chains and alliances (`has_successor`, `has_predecessor`, `is_alternative_to`).

The three concepts at the bottom right of Figure 3, namely `Procedure`, `Goal` and `Function`, are used to formally describe the methods' contexts, resp. its comprised procedures (*cf.* section 3).

An instance of the class `Procedure` can either describe this method's procedure in textual form with the given RDFS properties (*rdfs:comment*, *rdfs:seeAlso*, *rdfs:label*, ...) or can be linked to more complex constructs, like a class `Document` (not part of the figure) which again may link to a document in the file system. Otherwise, if a method makes use of another method, object properties, like `is_component_of` shall be used.

Taking into account, that a method is always purposeful and therefore always focused on a solution of a problem or task (Lindemann, 2009), a `Method attains` the concept `Goal`. The method's `Goal` is the class that can describe the method's contribution to the enterprise's strategy or overall value creation. For example, we can create the classes `ProductAssurance` or `VehiclePropertyAssurance` as a `Goal`'s subclasses. When a specific method assures an arbitrary business product, the respective instance can be linked to the `Product` of a product ontology.

Usually, a `Method` is `supported` by a number of `Tools` that are to make its application more effective and efficient (Lindemann, 2009). The term and therefore the respective class `Tool` covers a wide range of different auxiliaries or assistive equipment. In the domain of CAx, this can be all kind of testing equipment, physical implements, simulation or modeling software, but also arbitrary business software, statistical analyses or something totally different. Besides, the term also comprises simple assistive things, like forms, checklists etc.

## 4.2 Extending the Method Ontology

Up to now, the introduced method model allows to observe and compare methods based on their semantic context information, assumed the appropriate SPARQL queries have been implemented, for instance, the application of methods and tools during a specific process can be queried. Additionally, we further extend the method ontology with other ontologies, covering metrics, resources, descriptions, enterprise vocabulary etc., in order to model and be able to analyze a company's method landscape in a holistic way.

Due to limited space, we can only introduce the overall architecture and a summarized description of the created ontologies, though.

One of the big advantages of using Semantic Web technologies is having this vast amount of publicly available community ontologies, for instance, FOAF (Brickley and Miller, 2014) or SKOS (Isaac and Summers, 2009), that can be used as extensions, geared to the company's needs. The architecture presented in Figure 4 illustrates how our core method ontology is integrated as an upper ontology.

The remaining ontologies, e.g., a process, resource and metrics ontology, are mapped to the core ontology.

Independent from the chosen mapping paradigm between the ontologies, a company wants to model its own KB, covering their use cases. This domain ontology is depicted in Figure 4 as *Method Ontology X*.

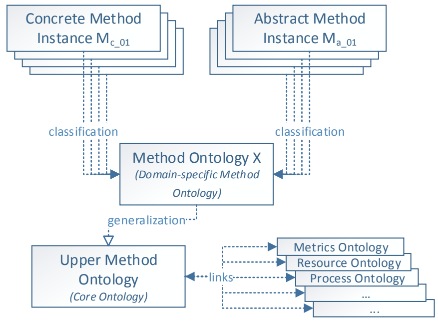


Figure 4: The method ontology's architecture.

The domain ontology specializes the concepts of the upper ontologies with domain specific ones and provides the TBox for our specialized assertions (ABox), i.e., *Concrete Method Instances* $M_{c\_u}$ and *Abstract Method Instances* $M_{a\_v}$.

For instance, it can be used to provide a necessary taxonomy for the domain of CAx methods by introducing new concepts, e.g., `CAE Method`, `CAD Method` and `CAT Method` or a more general method, like *dc:MethodOfInstruction* from Dublin Core. Along with new kinds of methods, apposite, more specialized metrics or other arbitrary parameters can be introduced in the same way.

The knowledge for creating an own domain-specific ontology can either be acquired from existing company sources, like documents, or from experience, by interviewing experts as described in the ONTORULE methodology (de Sainte Marie et al., 2011).

In order to compare methods based on their KPIs, for instance, the method's cost, input and output quality, maturity or duration, we developed a metrics ontology, covering the required quality attributes. Next to selection criteria, the metrics can act as indicator for strengths and weaknesses in the company's method framework and allows to detect gaps, e.g., processes that are scarcely supported by methods. This information is valuable for the strategic method development. The model can also be extended with arbitrary execution or evolution quality attributes (the so called "ilities"), like usability, reliability, manageability etc. Which kind of non-functional requirements to choose is facultative and up to the company's knowledge and methods engineers.

In accordance with the distinction between concrete and abstract methods (section 4.1), we also distinguish between `Concrete Resources` and `Abstract Resources` in the developed resource ontology. This model covers the required inputs and produced outputs of our methods. When modeling an `Abstract Method`, the knowledge engineer can define the type of resources that are required or produced by this method, for instance, a general placeholder parameter for an abstract CAD model name. But not until the `Concrete Method` instance is modeled and assigned to a process action, the `Concrete Resources` can be named, for example, a particular drawing. Following current best practices, like the example of the W3C Product Modelling Incubator Group (W3PM, 2009), our resource ontology, is influenced by a standard product model, namely STEP (AP 214/242) (ISO, 2014). We decided not to model a product's inner structure, like PDM systems do, but to confine ourselves with more abstract concepts, because our method ontology's purpose is still to model only the meta level of the method landscape, i.e., analogous to the method concept, we treat the products as a black box.

Furthermore, we have used SKOS to manage the heterogeneity of the enterprise's vocabulary, i.e., methods and policies, like regulations (Omrane et al., 2011). This way, multiple labels can be annotated to all the ontology's entities which makes them generally intelligible, e.g., by enabling a multilingual use or making the semantics more comprehensible for people with differing professional backgrounds.

# 5 ENTERPRISE INTEGRATION

The main objective of this integration has been a combination of method knowledge with an EAM in a product development division. This way, the input of strategic, business and IT decisions on methods and vice versa can be easily inferred, while the knowledge can be maintained independently.

Integrating our method meta model into an EAF bears many advantages. First of all, the combined meta models allow stakeholders to perform novel kinds of analyses, like impact analyses or discovering business and IT relations. For example, the concern "Which system/application supports which methods?" or the responsibility of the modeled actors and roles can be identified. Furthermore, a company benefits from such a mapping approach through a concerted and defined meaning of the modeled concepts and vocabulary. OWL, especially the extension SKOS, supports the use of various labels, hence different vocabularies can be attached to the concepts, if required.

As a prerequisite for the integration of our method meta model into an EA meta model, we first need to obtain a formalized model. We have decided to use TOGAF and ArchiMate as a foundation for our EA model because of their popularity and maturity. However, the Open Group does not provide a formalized model of their framework but considers TOGAF as an approach that should be further refined and implemented. Nevertheless, using ontologies and other Semantic Web technologies for the realization of EAs has been done for years now (Ortmann et al., 2014).

As a consequence and inspired by the above mentioned EA frameworks and meta models, we also created our own EA ontology. Since our method meta ontology has been realized using OWL, we also applied this language when designing our EA ontology, depicted in Figure 5.

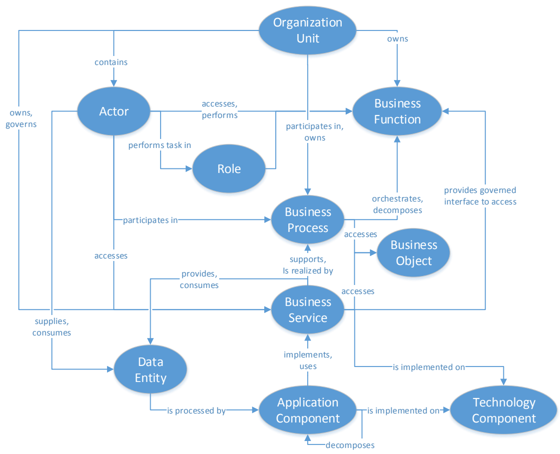


Figure 5: Enterprise Architecture ontology based on TOGAF and ArchiMate meta models.

An important requirement for this EA ontology has been a suitable coverage of the concepts known from our core method meta ontology, together with the extended method ontologies. Thereby, we want to make use of newly generated relations, for instance, from methods to business objects or capabilities. The TOGAF Core Content Metamodel, combined with the Archimate Design approach fulfill this requirement and can be extended when specialized concepts are needed as illustrated in Figure 6. We use the same generic concepts (OWL meta model) and extend the EA concepts with a more specific domain meta model.

After selecting the EA model, we need to establish mappings from our method ontologies' concepts and entities to the already existing elements in the EA.

Technically, we could pursue different mapping techniques for combining our ontologies: we could use the other ontology's concept URIs directly, which is the standard way in Semantic Web. For example, by importing the ontology into ours, we can use *ea:BusinessProcess* as a replacement for our *method:Process* in the method ontology. However, a fundamental idea behind our integration is the retained separation of both KBs, because each domain

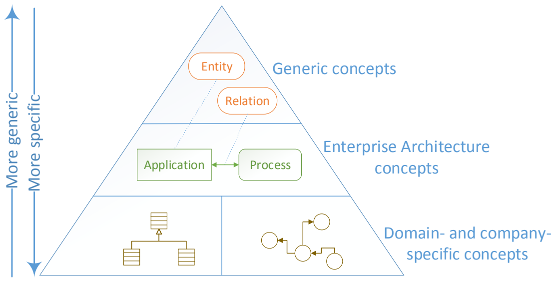


Figure 6: Meta models at different specificity levels (after (The Open Group, 2013)).

– the method knowledge and the EA knowledge – is the particular responsibility of a dedicated organizational unit and hence, changes in the other ontology can be opaque. An alternative option would be to use an upper ontology, like UMBEL (Giasson and Bergman, 2015), which is certainly a reasonable choice when combining lots of domains. We do not need such an explosion of our domain for the scenario at hand, though. The technique we have chosen to map the TBoxes is the use of an own mapping ontology for combining the various concepts, for instance, by using *owl:equivalentClass* or *rdfs:subClassOf*. This option can be implemented very fast, the mappings are traceable in one ontology, and it offers a good overview for a manageable amount of concepts, which is sufficient for the prototypical introduction presented in this paper.

Furthermore, next to matching the ontologies' TBoxes, we make statements about the individuals in the ABoxes that represent our model. The respective individuals, e.g., the modeled processes, are usually matched using OWL notation, as in *owl:sameIndividual*. However, it is often the case, that two individuals are only nearly exactly the same. Therefore, the use of a 'Similarity Ontology', along with object properties like *so:identical*, is a good idea. It allows to express different levels of identity (Halpin et al., 2010).

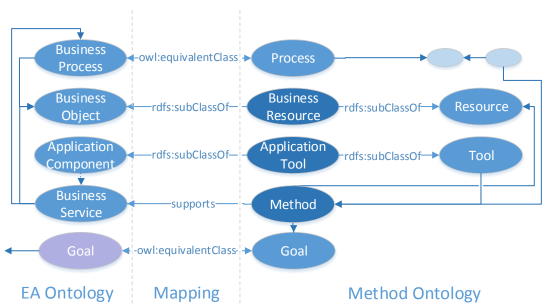


Figure 7: Mapping of EA and method ontology.

When comparing our core method ontology's with our EA ontology's concept names, we encounter some obvious similarities. An equal or similar name, however, does not automatically infer synonymous semantics. The considered key concept `Process` from our method ontology and the concept `Business Process` from the EA ontology are identical, though, especially when regarding the TOGAF "Process Modeling Extension". The conceptual mapping between both ontologies is depicted in Figure 7. We state that both concepts are equal even though the different processes can vary in their granularity.

Our intentions for the methods' input and output `Resources` are semantically covered by the concept `Business Object`, known from the ArchiMate Business Layer Metamodel. This concept "represents a business entity (e.g. an invoice) that is used during the execution of a business process" (Buckl et al., 2008). Processes can perform all kind of create, read, update and delete (CRUD) operations on a business object, which either represents a virtual or physical object (or both) (The Open Group, 2013). This applies to our methods' relations and the corresponding resources, as well. However, only a subset of the modeled EA business objects are pertinent for the analysis of our meta method ontology and vice versa. Therefore, both concepts share the common subclass `Business Resource` (*cf.* Figure 7). This subclass is modeled in a domain ontology, importing the upper method ontology.

The same reasoning applies to the concepts `Tool` and `Application Component`. A lot of business software is of no interest for the method domain and tools of the method domain can also include physical devices and implements. Consequently, we introduce the concept `Application Tool`. The various individuals in the ontologies' ABoxes are then mapped to their counterpart using properties that express the appropriate similarity.

Additionally, `Methods` represent a link between `Business Services`, process actions and tools. They express, how and when a business service can be applied to a specific process.

The final depicted mapping between both ontologies deals with the motivation extension, since methods as well as stakeholders in EA intend to achieve a `Goal`.

The remaining concepts of the core meta method model feature no counterpart in the EA ontology, even though both models feature a concept named `Function`. A function in TOGAF "delivers business capabilities closely aligned to an organization [...]. Also referred to as 'business function"' (The Open Group, 2011), whereas a function in our meta method model represents an appropriated behavior of a technical system (Weigt, 2008).

## 6 EVALUATION

The combination of an enterprise architecture with our method ontologies and the respective domain models enable methods engineers, enterprise architects, domain experts and other stakeholders to conduct novel kind of analyses. For example, we can compare and hence select the most suitable methods, based on the modeled KPIs, at specific process phases in the product development. Furthermore, a purposeful development and shutdown of methods is made possible by performing analyses based on the baseline and target architectures.

The new concepts and contributions, namely the use of standard Semantic Web languages, the EA integration, the evolved method meta model, along with the extending ontologies and the corresponding queries and rules, have been modeled, formalized and executed with a chosen set of test scenarios that showcase the proof of concept.

An earlier, specialized version of the introduced method meta model, together with a prototypical implementation as seen in Figure 8, has been developed and published during the FP7 ONTORULE project (Rosina and Kiss, 2011). This demonstrator proofs the feasibility and illustrates the benefits of our approach. However, it has been implemented using an alternative knowledge representation and rule language (ObjectLogic), covering a tailored meta model that realizes a particular automotive use case.

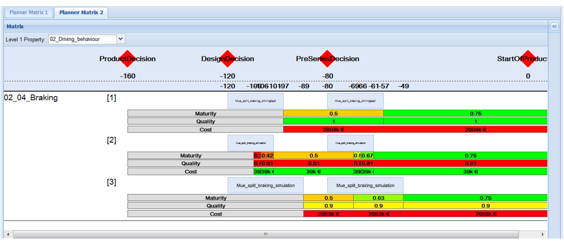


Figure 8: Extract of the demonstrator showing various possible method applications (Rosina and Kiss, 2011).

## 7 CONCLUSION

The developed ontologies presented in this paper depict the domain of design methods, including their context information, for instance, references to the processes they are used in, quality attributes and the methods' in- and outputs. This allows us to predicate statements on expected qualities, costs, time consumption or other KPIs which is a strong motive for domain experts when selecting an appropriate method best suited for the task at hand. They have been realized using Semantic Web standards, however, we omitted almost the entire technical part in this paper, concentrating on the conceptual models. A former technical realization is referenced in the evaluation section, though.

Another novelty is the integration into an EA ontology, which bears many mutual benefits. It enables the analysis of relationships on a strategic level, fostering a targeted method development, on the business level, e.g., between roles, processes and methods, and also on a business to IT level, for instance, by providing an overview of the applied method software tools.

However, the application, documentation, the execution and the maintenance of a formalized method management is expensive, can be complex and is wedded to effort, because it is mainly a manual procedure.

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# Model-Driven Architecture for SLA Orchestration in Cloud Services Based Systems

Assel Akzhalova, Akylbek Zhumabayev and Ulan Dossumov
[1]*Department of Electrical Engineering and Computer Science, Kazakh-British Technical University, Tole bi, Almaty, Kazakhstan*
*a.akzhalova@kbtu.kz, akylbekz@gmail.com, ulan.dossumov@gmail.com*

Keywords: Model-Driven, QoS, SLA, cloud, cost, protocol.

Abstract: The aim of MDA is to facilitate an entirely component-based system generation from models which are presumably small and manageable. It enables the system developing process be scalable meeting fast growing e-business demands. The system definition can be mapped to many possible platform infrastructures including those that are built on cloud services. Basing on MDA concept cloud services can be introduced by different providers offering and loaning available physical resources for a limited requested time by predefined contract containing service specifications. The service specifications and service provider's obligations are the elements of Service Level Agreement (SLA) that is a contract over the quality of service (QoS) and the violation of QoS may be a part of the contract between parties described as penalty policy. This paper proposes a system architecture of cloud computing infrastructure with dynamic QoS and SLA included that enables fair cloud resources facilitation.

## 1 INTRODUCTION

An efficient mechanism of interactions between clouds provides a way to enhance the capabilities of one of them. Such inter-cloud resource sharing requires dynamic resource allocation. Using Service Level Agreement(SLA) is vital in such dynamic environment. The cloud consumers expect high quality services delivered by certain cloud computing providers since they pay for them.

An example of use-case dynamic cloud service request and approval by the merging of providers' resources according to SLA and and Qos can be formulated as follows. We assume that there is available information about providers with the same cloud services. The user' requests can be handled by one provider that can request additional resources from the given pool of providers which is possible only according to predefined SLA. In other words, we can consider user as the provider requesting for resources in case if he needs some. Therefore, providers can create QoS documents to describe their minimum expectations from their services. The violation of QoS causes some form of penalty for participants. As a result, the provider reconfigures SLA object if there occurs any need to change current configuration of its cloud. Hence, a provider can share his available resources with others who needs more resources due to overload. When users request the service from the provider they have to agree on certain parameters of the SLA before they can continue to use the cloud. Upon successful agreement the user is permitted to reserve a certain amount of resource that is described in the SLA. Obviously, providers have to keep track of resource usage of every user. Afterwards, involved providers charge users based on their usage history and pricing plans. Figure 1 below shows described scenario as particular use-case.

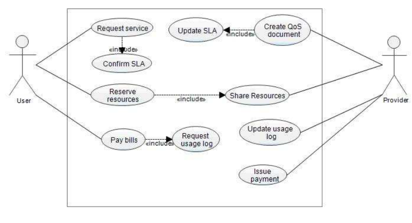


Figure 1: Use-case of user and provider interaction modeling of SLA and QoS-aware cloud service system.

Figure 1 demonstrates run-time system of the SLA and QoS based framework that typically may happen in case of shareable resources by cloud providers already signed SLA and cannot change fixed parameters and, therefore, do not take into account dynamic cloud service allocation.

For instance, (Keller and Ludwig, 2003) describes the Web Service Level Agreement (WSLA) framework that define and monitor SLAs for Web Services using WSLA specification language. The WSLA language is based on XML and it is defined as an XML schema. According to WSLA, Service provider signs up a contract that is the WSLA document to perform a service according to agreed guarantees for service level parameters such as response time and throughput, and measures that have to be taken in case of violation and failure to meet the asserted service guarantees (Figure 2).

```
<!– Global WSLA structure –>


<xsd:complexType name="WSLAType">
  <xsd:sequence>
    <xsd:element ref="wsla:Parties"/>
    <xsd:element name="ServiceDefinition" type="wsla:ServiceDefinitionType"
                         maxOccurs="unbounded"/>
    <xsd:element name="Obligations" type="wsla:ObligationsType"/>
  </xsd:sequence>
  <xsd:attribute name="name" type="xsd:string"/>
</xsd:complexType>

<xsd:element name="SLA" type="wsla:WSLAType">

</xsd:element>
```

Figure 2: WSLA structure.

The typical template of WSLA consists of three main parts: Parties, Service Definitions and Obligations. Parties means the parties involved in the management of the Web Service. Service Definitions contains an information about the services the WSLA is applied to such as service actions and service parameters and metrics. It also describes measurement methods of a service's metrics. Obligations specify the service level that is guaranteed with respect to the SLA parameters. A service provider can specify price for each providing service. However, the price must be defined in advanced and it is fixed regardless of current loading or provider's (consumer's) preferences.

Thus, one of the most important problems that providers of cloud services have to tackle is the fair method to charge customers for the real cloud utilization. However, the frequent resource allocation upon new arrivals of tasks make it a challenging problem to construct the system containing a combination of available resources along all the SLA parameters that would cater user requirements.

Ideally, once when current service becomes expensive to use by current customer, the system should automatically binds cheaper but faster service in order to meet SLAs and QoS. QoS and SLA monitoring are able to retrieve important parameters from the available running services which can be used in future for better adaptation. This approach can be an attractive solution in more complex case when cloud service providers might organize temporal agreements for cloud merging.

Thus, an efficient solution of service-oriented cloud computing should consider dynamic configuration of SLA that varies across all stakeholders of the cloud (Groleat and Pouyllau, 2011). The providers should understand a potential risk of customer dissatisfaction caused by delivery of services of low quality. Business operations force QoS requirements to be dynamic and adjustable to the operational environment.

In this paper we present a meta-model of the cloud services based system applying MDA. The MDA based framework can be considered as one that finds best cost for each cloud provider at run-time in order to provide maximum profit to keep desirable performance and QoS parameters. This architecture can be scaled up by allowing the deployment of multiple service instances running on different cloud servers. We analyze interaction between the system performance, QoS and SLA measures and introduce monitoring engine as an additional instrumentation of SLA observers that are generated from the initial meta-model.

The choice of appropriate cloud service resources is defined by policies that show QoS characteristics and SLA parameters. It is essential to design and implement admission control mechanism that will be able to conduct best cloud service allocation in order to introduce cloud service composition framework supporting QoS.

According to the generated SLA observers and QoS we introduce SLA based orchestration for flexible and fair cloud resources facilitation and meantime providing best deal for cloud service providers. Section 2 introduce MDE approach for SLA and QoS-aware system architecture. Section 3 describes SLA observers and generation cloud merge protocol for the proposed architecture. Section 4 demonstrates Case study. Section 5 compares different techniques that base on policy-aware service composition. Section 6 summarizes contribution and results.

## 2 MODEL-DRIVEN ENGINEERING FOR SLA AND QOS-AWARE SYSTEM ARCHITECTURE

Model-Driven approach provides interoperability and reusability of SOA systems by settling and manipulating a set of interoperable metamodels at different layers of abstraction. The role metamodel is mainly to enable future automatic transformations between models which makes the software development more efficient. The specification and design of services within a service-oriented architecture proposed by OMG standard introduces Model Driven Architecture (MDA) to model SOA. MDA for SOA separates the logical representation of a service from its possible implementation on various platforms through auxiliary transformation the platform independent model to a platform specific model by maintaining mapping functions which are collection of rules and algorithms. In SOA prospective, these rules can be regarded as policies for a design-time and run-time service composition via model transformation (see for example, (Gönczy et al., 2009), (Bocchi et al., 2008), (Cortellessa et al., 2007)).

The life cycle of policy enforcement on these levels includes policy description and repository, adaptation and monitoring. The policy repository stores format or policy expression and can be formalized by simple using constraint language. Adaptation is conducted under service control engine. Service control engine selects a service provider from a number of service providers having their service details, in particular: service quality attributes and SLA.

This work presents a model-driven framework for policy generation to select the service provider as matching technique that comprises of judging from negotiation of service functionality and cost. We include to the system architecture monitoring component that collects metrics or statistics to support the process of checking for policy compliance. After observing the adaptation for an initial policy definition, the policy may be modified to better align with the specific objectives. In particular, we suggest that the relationship between possible reconfigurations and QoS constraints should be incorporated into the design of a SOA: the additional complexity providing significant benefit at runtime through automated policy generation. Our focus will be on meeting QoS constraints (performance and reliability) for an overall architecture, what we consider as Service Level Agreements (SLAs). Figure 3 shows the system architecture of handling requests by several cloud providers using proxies and controllers.

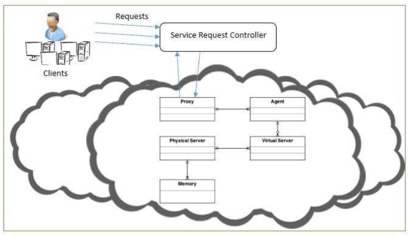


Figure 3: An architecture of the cloud system handling requests by multiple providers.

In Figure 3 there are several parties and components: Users, Service Request Controller, Physical Machines, Virtual Machines, Agents and Proxies.

**Users/Clients** Users are involved in the system since they send service requests to the clouds for processing.

**Service Request Controller** is an interface between the clouds and users/clients. It is responsible for resource management and allocation. Governed by SLAs, it manages the interaction of the clouds in order to fulfil QoS requirements set by users and other providers.

**Physical Machines** . As every provider has physical machines that includes memory and storage physical machines are responsible for consuming, processing and monitoring requests on physical level.

**Virtual Machines** can run on a single physical machine. They act as a logical layer in the operational hierarchy. VMs are responsible for physical resource allocation, memory usage, processing and monitoring requests on application level.

**Agents** are responsible for storing information on their providers, such as: current bandwidth, memory, storage capacity, CPU load and current number of requests.

**Proxies** We assume that each provider has its own set of proxies that receive requests particular for its provider. These proxy servers eventually tell controller about their throughput, number of requests and server load such that controller can reallocate resource among different cloud service providers based on SLA.

The scenario of processing user's request works as follows:

First, user's request for a particular service *S* from Provider *A* goes to Service Request Controller. Service Request Controller redirects the request to the provider's Proxy. Proxy of the specified provider sends the request to physical servers that can process the request. Service Request Controller redirects the request to the provider only if there is a confirmation from provider that it is able to proceed. Otherwise, if original provider cannot handle the request by itself, it requests extra resources from other predefined providers based on the SLA between them. Meantime, an information about status of providers are monitored by Agents that provide current loading of virtual machines in order to fulfil SLA parameters.

In our work we offer MDE for cloud based system that identifies meta-model and relationships between the following components: Cloud based system, Controller, and Monitoring. The metamodel includes:

- a QoS constraints defined by UML for QoS profile;
- model transformations that: 1. generates SLA objects taking QoS specifications of how an architecture should evolve in the face of QoS constraint violations for the adaptation engine; 2. generates self-organized pattern for SLA protocol that Agent constructs automatically in order to quickly to changes the service binding.

As it can be seen from Figure 4 the dynamic service composition can be implemented by applying policies which are based on QoS requirements and SLAs. The service handling can be considered as model transformations MT): MT1, MT2, MT3 (Figure 4 which makes reconfiguration of the architecture.

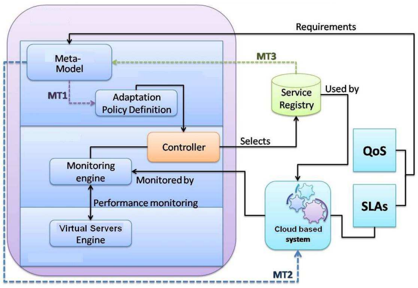


Figure 4: Model transformations for the Cloud based infrastructure.

The model transformation MT1 is able to automatically frame the appropriate cloud provider which is realized by Open Shortest Path First (OSPF) algorithm to find the clouds that have highest throughput and is available to share resources at the time of particular request, over which our dedicated Agent can determine reconfiguration strategies (choices over variant points) as a function of environmental changes. This resulting policy table is then combined with a mapping from choices to actual actions on the implemented system, to provide a runtime adaptation engine.

We employ model transformation MT2 in order to extract application metadata from the design time metamodel, with the purpose of understanding how the system is configured at runtime and, consequently, what needs to be monitored:

- Deployment data for individual services (location, interfaces, etc);
- The initial architectural configuration of services (what usage connections exist between services);
- The basic properties that are necessary to compute values of the QoS characteristics used in the model: memory, number of requests, throughput, response time and storage capacity.

A third model transformation MT3 is then used over this monitoring information to change the information associated with individual services in the repository model. Policy generation, as it will be discussed in the next section, is modeled at design-time as a possible transformation that an architecture model can undergo, representing possible reconfigurations of service composition based on self-organized pattern. Therefore, service selection allows us to consider the reconfiguration of an architecture as a *transformation* from one SOA for Cloud based model instance to another.

# 3 AUTOMATIC SERVICE COMPOSITION BASED ON SLA AND QOS

The metamodel is equipped with QoS characteristics and SLA that computes the overall cost as a function of time of architectural configurations that has to be minimized.

QoS parameters are defined at runtime due to the dynamic negotiation processes upon new service requests. For instance, required amount of memory, bandwidth, storage capacity, response time, throughput are QoS parameters that are embedded to SLA which calculates the cost. At the stage of MT1 the new SLA object *newSLAObject* is created and it consists of the following fields:

- memory
- number of requests
- throughput
- response time
- storage capacity

The cost of handling the service we calculate taking into account switching price between $k$ providers, $m$ VM that able to process request by allocating memory and storage as well as time penalty if the request is processed overdue and price of data transfer:

$$\begin{aligned} \mathrm{cos}t = N \cdot \Big\{ \sum_{i=1}^{m} (CostVM_i + CostMem_i \cdot 3600 + \\ + StorCost_i \cdot 3600) \Big\} + TranferCost + \\ + \sum_{i=1}^{k} SwitchCost_i - \sum_{i=1}^{m} PenaltyCost_i \end{aligned}$$

where $\mathrm{CostVM}_i$ - cost of using a virtual machine $i$ triggered by the incoming request (*perhour*), CostMem is the cost of using memory belonging to working VM (*persec*), StorCost is the cost of using a physical storage (*persec*), TransferCost is the cost of data transfer per hour (*perGb*), SwitchCost is the cost of requesting resources from an additional cloud, PenaltyCost is the time penalty (*persec*), $N$ is a number of requests, $m$ is a number of virtual machines triggered by all user requests during an hour, $k$ is a number of additional clouds (providers) triggered to process all requests during an hour.

SLA negotiation is based on the constraint satisfaction. For instance, preferred price set by a requesting provider for a particular service should be either declined or accepted by an offering provider. However, our main goal is to maximize profit for all providers by sharing their idle resources. As a result, overloaded cloud service providers will still be able to respond to user requests by leveraging available resources from other providers having low resource consumption. At the same time, it will be beneficial for providers to lend their resources instead of keeping them idle for uncertain period. Thus, the values of the variables in 3 are negotiated during the service discovery and binding. The process of dynamic allocation of resources to meet SLA is autonomously handled based on the following Policy which is implemented by Service Request Controller:

1. A new request is received
2. SLA negotiation process is starting
3. Estimating QoS
4. If estimated QoS violated desirable QoS then Service Request Controller analyzes the number of extra resources and finds a third-party provider to satisfy QoS requirements by forwarding requests to negotiated resources issued by the third party.

For instance, Service Request Controller handles SLA negotiation process and estimates time duration of processing a request by cooperation with Agents and Proxy of current provider. The set of proxies that implement Proxy engine informs the Agent about current workload of VMs including available memory, CPU and number of requests.

MT2 is considered as Protocol that facilitates the negotiation process between participating cloud computing providers. Specifically, Protocol enable automatic procedure of service discovery and binding by the middleware between providers based on their functional and non-functional requirements.

Cloud providers either reserve or lend resources by constantly adjusting prices based on individual strategies and it might be represented in a form of competitive game, in particular, so-called winners in the minority. In other words, the worst 'player' in the majority will have to change its protocol parameters. Krothapalli and Deshmukh describe this scheme where cost is considered together with a process completion time (Krothapalli and Deshmukh, 1999). The amount of cost depends on the due date and the processing time. A customer requests bids from the providers. After some period the customer may refresh the request again to eventually select a certain bid.

In this work we introduce model transformation MT2 that allows automating the configuration of the cloud providers negotiation and generates Protocol which is designed to provide the newly connected clouds having configuration parameters required by QoS and specified in SLAobject. Basing on SLAobject the new cloud should be able to communicate with another cloud automatically as shown in Figure 5.

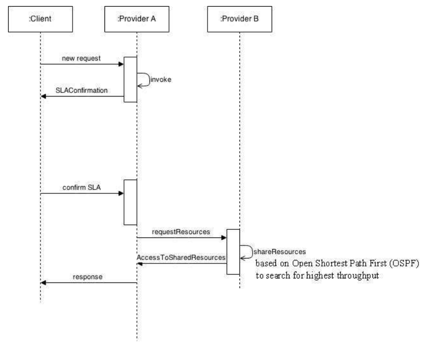


Figure 5: Protocol of binding services.

Protocol is derived from Open Shortest Path First (OSPF) to search for cloud provider with the highest throughput. An original form of OSPF calculates the shortest path to all known destinations connected to the network (Le Sauze et al., 2010). In our metamodel we employ this algorithm to share resources according to the highest throughput which is taken into account in MT1 to calculate cost. OSPF protocol has the following states: Down state, Init state, Two-way state, Exchange start, Exchange, Loading, Full adjacency.

In our case, we refer Down state to the state when particular cloud is inactive. The inactive cloud does not exchange any messages with others and waits for the next state. Initial state we use for the state when particular cloud sends "Hello" packet to the Service Request Controller in order to learn about all active clouds participating in the network. In Two-way state state the cloud that has sent packet "Hello" receives the packet back which means the connection has been established between the cloud and the Service Request Controller. Afterwards, the cloud can change the state to Exchange state in which it actually starts sharing its own resources. Loading state is the state when the cloud starts being loaded up. When the cloud is involved actively in the sharing process then its state becomes Full Adjacency in which it does not need to send initial packets in order to introduce itself to the available pool of cloud providers.

Therefore, we can demonstrate Protocol described above as follows in Figure 6, Figure 7 and Figure 8. For instance, Figure 6 considers step when new cloud joins the composition it should send ANNOUNCE request to introduce itself to the group members. Figure 6 considers step ASKRESOURCES to request needed resources and request ASKRESOURCES is immediately followed by the request SHARERESOURCES in order to ensure that the requesting cloud is still operating shown in Figure 8.

**PROTOCOL** Request ANNOUNCE
SLA Parameters:
idData: cloudId
var: memoryAmount
var: storageCapacity
var: minimumThroughput
var: maxCost
var: responseTime
Response ANNOUNCE
Response Status:
var: statusCode

Status code can be one if the following:
*1xx: Informational* - Request received, continuing process
*2xx: Success* - The action was successfully received, understood, and accepted
*3xx: Redirection* - Further action must be taken in order to complete the request
*4xx: Client Error* - The request contains bad syntax or cannot be fulfilled
*5xx: Server Error* - The server failed to fulfil an apparently valid request

Figure 6: Protocol: Step ANNOUNCE.

**PROTOCOL** Request ASKRESOURCES
SLA Parameters:
idData: primaryCloudId
idRequestedCloud: foreignCloudId
var: storageCapacity
Response ASKRESOURCES
Response Status:
Var: StatusCode

Figure 7: Protocol: Step ASKRESOURCES.

**PROTOCOL** Request SHARERESOURCES
SLA Parameters:
idData: primaryCloudId
idRequestedCloud: foreignCloudId
var: storageCapacity
Response SHARERESOURCES
Response Status:
Var: StatusCode

Figure 8: Protocol: Step SHARERESOURCES .

We consider QoS constraints as it was presented in paper (Akzhalova and Poernomo, 2010). After cost model has been defined and QoS requirements are determined and included into SLAobject the model transformation MT3 automatically changes the global configuration of the system to adjust it to desirable state. An idea of adaptation is derived from paper (Akzhalova and Poernomo, 2010) when the system adaptation happens by calling Reconfigure() selftransformation to make the system satisfy to desirable QoS characteristics which are pre-defined in QoSConstraints. In this work Reconfigure() generates Policy which is used then for a Binding appropriate Service by Service Request Controller. Therefore, Reconfigure() produces Policy as a product of the following transformation:

$$\textbf{Reconfigure} : System \times QoSConstraints \times SLA \rightarrow Policy \quad (1)$$

where reconfiguration of System is evaluated by its cost model defined by CostFunction which was described in previous section.

Every TimeStep when System violates QoSConstraints, Recongigure() defines Service.ID that has to be bound for each service request. We designate a candidate Service as $\{Policy(TimeStep) = ID, ID = 1, ..., NumberofServices\}$.

To find best candidate service at each time step:

$BestPolicy(TimeStep) \in \{Policy(TimeStep) = ID,$

$ID = 1, ..., NumberofServices\}$

that satisfies to QoS constraints:

$$Constraints() \equiv true$$

and gives a minimum to an overall cost of the System:

$$System.CostFunction(Policy) \rightarrow \min, \quad (2)$$

where System changes its reconfiguration according to System.SystemConstraints():

$$SystemConstraints(TimeStep, Policy(TimeStep)) \quad (3)$$

# 4 EXPERIMENTS

The purpose of this experiment is to find out how proposed QoS and SLA aware infrastructure affects to performance of the cloud based system and relationship between cost and performance.

For simulation purposes, we take two Data Centers (DC) and four User Bases (UB). User Base is a group of users taken as single unit for the simulation purposes. User Bases are sources of traffic. An information about User Bases and Data Centers are given in Table 1, 2 and 3, respectively.

For the sake of simplicity, we have taken peak hours independent from regions. We implement analysis of handling multiple requests from different locations for duration period 30 days (approximately

Table 1: User Base specifications.

| Name | Region | Requests per User | Fixed Data Size per Request | Avg Peak Users | Avg Off-peak users |
|---|---|---|---|---|---|
| UB1 | 2 | 60 | 100 | 1000 | 100 |
| UB2 | 1 | 100 | 100 | 1000 | 100 |
| UB3 | 1 | 50 | 100 | 1000 | 100 |
| UB4 | 0 | 60 | 100 | 1000 | 100 |

Table 2: Data centers allocation.

| Region | Cloud Id |
|---|---|
| North America | 0 |
| South America | 1 |
| Europe | 2 |

Table 3: Data centers specifications.

| Data Center | #VMs | Image Size (bytes) | Memory | Bandwidth |
|---|---|---|---|---|
| DC1 | 5 | 10000 | 1024 | 1000 |
| DC2 | 5 | 10000 | 2048 | 1000 |

one month). We assume that there are 10 simultaneous users from single User Base requesting particular cloud service.

We consider case when number of requests from one user $N$ varies between 50 up to 100 per second, a number of virtual machines $m$ is 5 which are triggered by all user requests during an hour and $k$ which is number of additional cloud providers is 2.

The proposed Policy is used across VMs in single Data Center. The ”VM Cost” and ”Data Transfer Cost” calculated by following formulas:

$VMCost = totalTime * CostperVM/Hr$

$DataTransferCost = totalData/(1024*1024) * DataTransferCost$

Input parameters for cost function is given in Table 4.

Applying MDE approach proposed in this work we calculate Data Center usage cost and best cloud service provider that can be given automatically to process user requests shown in Table 5 and Table 6.

Table 7 displays maximum, minimum and avarege achieved response time for different User Bases and their regions allocation shown in Figure 9. As it can be studied from the Table and examining all accommodated systems we have detected that the best variant in terms of minimum cost and response time was generated by policy that operates with services with highest number of physical machines.

We observe that total cost of the system decreases while handling services when the value of their capacities increases. Therefore, there is an inverse relationship between performance of existing resources (services) and cost and response time of the system. Figure 10 demonstrates loading of Data Centers that process requests according to automatic configurations done by proposed framework.

All measures were classified in interval based category which based on time intervals experienced by the entity or by events passing through the entity. An example of an interval based measure is the average waiting time of events at a certain entity.

Figure 9: Dynamics of response time.

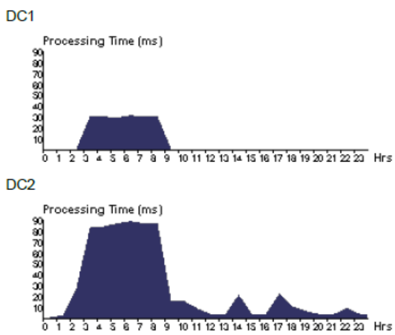


Figure 10: Dynamics of loading of the Data Centers.

Summarizing the case study, we have examined affection of changing number of requests, capacities

Table 4: Input parameters for cost function.

| CostVM ($/hr) | CostMem ($/s) | StorCost ($/s) | TransferCost ($/Gb) | SwitchCost ($) | PenaltyCost ($/s) |
|---|---|---|---|---|---|
| 0.001 | 0.0005 | 0.0001 | 0.1 | 3 | 0.1 |
| 0.003 | 0.0005 | 0.0002 | 0.6 | 3 | 0.1 |

Table 5: Data center usage cost.

| Name | Cost per VM | Memory cost | Storage Cost | Data Transfer Cost | Physical Hardware Units |
|---|---|---|---|---|---|
| DC1 | 0.1 | 0.05 | 0.1 | 0.1 | 2 |
| DC2 | 0.3 | 0.05 | 0.2 | 0.06 | 1 |

Table 6: Costs of using the clouds.

| Data Center | VM Cost ($) | Data Transfer Cost ($) | Total ($) |
|---|---|---|---|
| DC2 | 21,792.24 | 66.062 | 21,858.302 |
| DC1 | 7,263.61 | 109.848 | 7,373.458 |

Table 7: Response time estimated by regions and by User Bases.

| Userbase | Avg(ms) | Min(ms) | Max(ms) |
|---|---|---|---|
| UB1 | 308.5 | 209.79 | 36,726 |
| UB2 | 210.89 | 135.46 | 38,707 |
| UB3 | 210.19 | 136.54 | 34,079.3 |
| UB4 | 65.812 | 36.034 | 36,711.26 |

to the system characteristics such cost and response time:

- The experiments showed an automatic reconfiguration of the system that handles multiple requests from different User Bases according to the provided framework.
- The response time of the system differs significantly if the system process requests on more than one physical servers and therefore, with highest throughput.
- Employing OSPF gives better response time.

These investigations can produce essential recommendations when design cloud based system automatic resource allocation engine and struggle with workloads. The proposed Protocol and QoS and SLAbased reconfiguration can be used by cloud service providers to install dynamic SLA contract with service consumers.

## 5 DISCUSSION

(Cardellini et al., 2009) offers MOSES framework where SLA Monitor collects data about the average amount of requests from user, response time, cost of execution and reliability from both user and provider side. In (Cardellini et al., 2009) SLA Monitor notifies Adaptation layer about the fluctuation of current workload. However, the framework does not take into account the workload into the further model of adaptation. After receiving notifications and information about QoS attributes from Monitoring Layer, Adaption Layer is built over business process model and Adaptation Manager. The invocation of the business process causes generation of the new instance of the process which may differ depending on decision made by Adaption Manager. Therefore, Adaptation Manager solves new optimization problem for each new instance of the business process model. The optimization problem is represented by single objective optimization problem where the performance target is to make the distance between maximum values of QoS attributes and current ones as far as possible while meeting two types of constraints: negotiation between MOSES and each user and MOSES and providers. This problem was solved by linear programming approach. However, it has limitation in case of exponentially increasing number of concrete services. In this work we model the system where SLAs are measured and given from providers.

(Menascé et al., 2010) presents the framework that is a part of Model-Driven project SASSY (Self-

Architecting Software Systems). SASSY is a runtime of SOA self-architecting and re-architecting concept to meet functional and QoS requirements such as availability, execution time, and throughput.

In the SASSY framework, the domain expert has to specify desirable requirements using a visual activity-based language. Basing on these requirements The SASSY automatically generates a base architecture. This architecture will be optimized according to specified to QoS requirements through the selection of the most suitable service providers and application of QoS architectural patterns. Each service sequence scenarios (SSS) has own utility function that is related to one QoS metric and it is a subject to constraint. An overall utility function is used to adapt the whole architecture. The new architecture is created from the base architecture with the help of optimizing a utility function for the entire system. In our work we minimize overall cost function that reflects service providers's SLAs.

## 6 CONCLUSIONS

In this work we have offered distributed platform for QoS control and SLA based reconfiguration that allows to the cloud based system adapt at runtime depending on constantly changing QoS parameters by adjusting SLAs automatically by Service Request Controller engine. Therefore, service providers do not have to manually allocate service requests on fixed different servers. It will be done according to the predefined preferences and SLA contracts with other cloud service providers. The system reconfiguration will be done on QoS requirements in order to improve the performance of the system.

We have extended the meta-model proposed in previous works that selects best architecture by employing suitable OSPF optimization technique depending on requirement to the infrastructure. Therefore, it will provide QoS management of merged cloud systems.

The case study investigates how different parameters of the cloud system and SLA affect to the cost and performance. We have formulated recommendations for applying our approach to dynamically adapt cloud based system to desirable QoS characteristics.

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# Supporting the Security Certification of Cloud-Computing-Infrastructures

Amir Shayan Ahmadian[1], Fabian Coerschulte[1] and Jan Jürjens[1,2]
[1] *Chair of Software Engineering, Technical University Dortmund, Otto-Hahn Strasse 12, 44227 Dortmund, Germany*
[2] *Fraunhofer ISST, Emil-Figge-Straße 91, 44227 Dortmund, Germany*
*shayan.ahmadian@cs.tu-dortmund.de, fabian.coerschulte@cs.tu-dortmund.de, jan.jurjens@cs.tu-dortmund.de*

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Abstract: Outsourcing services into the cloud is a worthwhile alternative to classic service models from both a customers and providers point of view. Therefore many new cloud providers surface, offering their cloud solutions. The trust and acceptance for cloud solutions are however still not given for many customers since a lot of security incidents related to cloud computing were reported. One possibility for companies to raise the trust in the own products is to gain a certification for them based on ISO27001. The certification is however a large hurdle, especially for small and medium enterprises since they lack resources and know-how. In this paper we present an overview of the ClouDAT framework. It represents a tool based approach to help in the certification process for cloud services specifically tailored to SMEs.

## 1 INTRODUCTION

Cloud computing is a business model that kept gaining importance in the recent years. The National Institute of Standards and Technology describes cloud computing as “ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction” (National Institute for Standards and Technology, 2011). Cloud computing provides a very interesting opportunity for IT enterprises to service a large amount of customers by offering dynamic scalability, elasticity, and a cost model that is based on pay-as-you-go model.

The utilization of cloud computing services has been ever growing in the past years and the growth of this business model is expected to continue in the near future (Armbrust et al., 2009). However, the acceptance of cloud computing is growing slowly, due to the fact that cloud computing introduces new threats and vulnerabilities. Therefore, besides all the advantages of cloud computing, cloud providers need to convince the cloud customers of security.

A possible way to encounter scepticism and raise acceptance is the certification of cloud providers according to standards like ISO27001 (ISO, 2013). However, for small and medium-sized enterprises (SMEs), offering cloud solutions is a rather complex task, due to the lack of know-how and resources to conduct an ISO27001 compliant risk assessment and generate the appropriate documentation to reach the certification. The ClouDAT project (ClouDAT, 2015) offers a framework helping SMEs handling the certification process. It contains a cloud-specific risk assessment process and allows the automatic generation of ISO27001 compliant documentation based on the outcomings of the risk assessments.

In Section 2 we present a high-level overview of ClouDAT and introduce the risk analysis process. In Section 3 we deliver an in-depth insight into the underlying metamodel to introduce the key concepts of ClouDATs risk analysis. Based on this insight, Section 4 gives a detailed introduction into the methodology associated with the metamodel to point out the benefits that ClouDAT offers SMEs. Moreover, in Section 5, we introduce UMLsec (Jürjens, 2005a), an extension of UML for secure system development, along with the CARiSMA (CARiSMA, 2015) tool that supports UMLsec models.

# 2 THE SECURITY CERTIFICATION APPROACH

In the first step we introduce the structure of the ClouDAT framework and outline its risk analysis process.

## 2.1 The ClouDAT Framework

The result of the ClouDAT project (ClouDAT, 2015) is the ClouDAT framework. This framework is available as open source and supports SMEs by providing a means for certifying cloud services. Generally, the ClouDAT framework establishes an Information Security Management System (ISMS) based on the ISO 27001 (ISO, 2013) standard. The development of an ISMS allows organizations to implement a framework for managing the security of their information assets such as financial information, employee and customer information. The framework contains different parts:

- A metamodel for the risk analysis process complying with ISO 27001 standard.
- A metamodel for the risk treatment process complying with ISO 27001 standard.
- A catalog of security requirements.
- A catalog of cloud-specific threats.
- A catalog of security controls.
- Different editors to model cloud environment and use cases, security requirements, and security controls.

In the rest of this section, the above mentioned parts are described along with the ClouDAT risk analysis process. The metamodels are introduced in the respective sections.

## 2.2 The Overview of the ClouDAT Risk Analysis Process

Figure 1 (Alebrahim et al., 2014) presents an overview of the our risk analysis process, which complies with ISO 27001 standard. In the following, we summarize the different phases of the process.

### 2.2.1 Cloud Elements Identification

In this phase, the scope and the boundaries of the ISMS is defined. To this end, we employ the Cloud System Analysis Pattern (CSAP) (Beckers et al., 2011). CSAP provides a structured approach to describe cloud environments. It provides a framework to model their elements, such as data elements, physical objects, and stakeholders. Moreover, it describes the relations between the cloud elements.

The process of the asset identification starts with instantiating the CSAP. In the first step, the cloud customers and the required cloud services are identified. Then the cloud is instantiated, which consists of different types of cloud elements.

### 2.2.2 Refine Cloud Elements

This phase complies with Section *4.2.1 d* of the ISO 27001 standard. The main goal of this phase is to determine the cloud elements that are important to the risk analysis. Later, for these cloud elements, the risk analysis is performed. The results of this phase are collected in a table, which is called *cloud element list*. This table contains all mandatory cloud elements for the risk analysis.

The cloud elements refinement is performed in two steps (Alebrahim et al., 2014):

- Refine cloud elements and their location: In this step the abstract mandatory cloud elements are refined into more concrete and detailed cloud elements. Moreover, the location of the cloud elements are identified.
- Assign responsibilities and relationships: In this step the responsibilities of the cloud elements are identified and the relations between the cloud elements are determined.

### 2.2.3 Instantiate Threats and Vulnerabilities

In this phase, for all the cloud elements that were specified in the previous phase a threat analysis is performed. Generally, in the threat analysis, it is investigated whether a cloud element is endangered. Moreover, it is examined if a cloud element has vulnerabilities that can be exploited by a threat. In the ClouDAT framework a catalog of predefined threats and vulnerabilities for cloud elements is provided. This catalog is based on previous works, for instance (Cloud Security Alliance, 2011), (Heiser and Nicolett, 2008), (European Network and Information Security Agency, 2009). Additionally, the list of cloud computing top threats (Cloud Security Alliance, 2013) from Cloud Security Alliance (CSA) is considered. The provided catalog is a starting point for the threat analysis and should not be considered as complete.

### 2.2.4 Assess Risks

This phase complies to section 4.2.1 of the ISO 27001 standard. The results of this phase declare the existing risk to the cloud elements, and specify whether a cloud element requires risk treatment. Before starting the risk analysis, the risk approach and the risk acceptance level must be specified. Generally, the risk

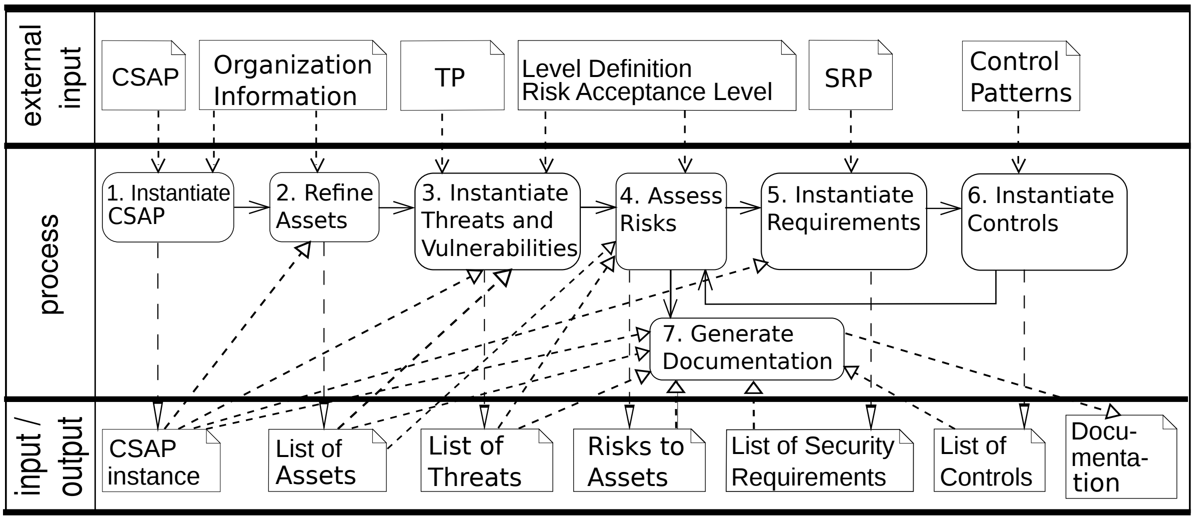


Figure 1: A snapshot from the control list.

assessment is based on the business impact, and the security failures. Business impacts express the consequences that affect the failure of the security goals. Furthermore, considering the threats and the vulnerabilities that are identified in the last phase, we need to determine the likelihood of potential security failures for all menaced cloud elements.

The multiplication of the likelihoods for the security failures and the values that are assigned to the business impacts estimates the risk levels of the cloud elements. By comparing the estimated risk levels of cloud elements and the defined risk acceptance level, the cloud elements that require risk treatment are identified.

#### 2.2.5 Instantiate Security Requirements

In this phase we consider all the cloud elements with an unaccepted risk level. We need to define a risk treatment method to reduce the risks. We comply with ISO 27001 Sect. 6.1.3 by defining and applying an information security risk treatment process. The ISO 27001 specifies the following treatments:

- Applying appropriate controls.
- Accepting risks.
- Avoiding risks.
- Transferring the associated business risks to other parties.

In Section 4 we describe our risk treatment method completely. In this section, we only summarize our method. Generally, if a cloud element has an unacceptable risk level, security requirements have to be defined. To this end, security requirement patterns (SRP) are defined (Section 3). In a concrete certification process, security requirement patterns are instantiated, and for each cloud element with an unaccepted risk level, a security requirement will be defined. ClouDAT framework provides a catalog of predefined SRPs.

#### 2.2.6 Instantiate Controls

Our risk treatment process complies with ISO 27001, and mainly contains applying appropriate security controls considering the security controls provided in Annex A of the ISO 27001. Generally, the selection of the controls is based on the cloud elements with unaccepted risk level, which are identified during risk assessment. Similar to security requirement patterns, the representation of the security controls is specified by control patterns (CP), and a catalog of predefined security controls is provided. As we mentioned above, we describe our risk treatment method in more details in Section 4.3.

#### 2.2.7 Generate Documentation

In the final phase of our risk analysis process, a document is generated. This document contains the list of refined cloud elements, the list of threats and corresponding vulnerabilities, the list of cloud elements with unaccepted risk level, the list of security requirements, and finally the list of selected controls to reduce the identified risks. The resulting documentation is used as a reference for the certification. In the following sections, we describe the underlying concepts

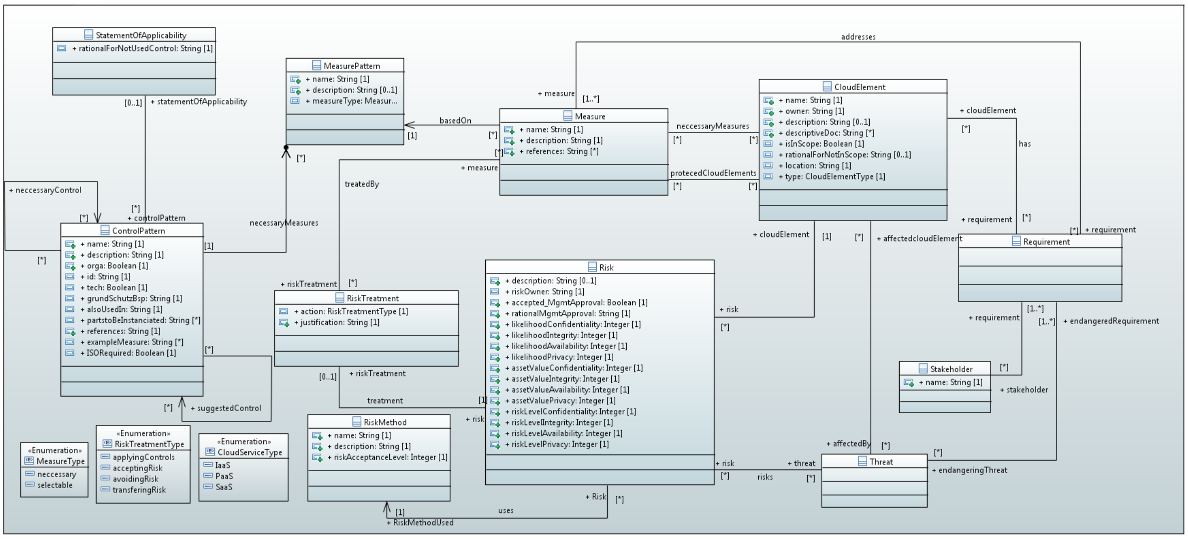


Figure 2: Risk analysis metamodel excerpt.

of the risk analysis process in more details together with the basic metamodels.

# 3 RISK ANALYSIS METAMODEL

This section describes the foundations of the risk analysis process in detail. Therefore, it takes a closer look at a simplified version of the risk analysis metamodel defined by the ClouDAT process.

Figure 2 shows an excerpt of the full risk analysis metamodel class diagram. Since we only want to discuss the key concepts, this illustration hides several classes and additional implementation detail.

The goal of the risk analysis phase is to identify the risks affecting the cloud elements that were found during the “Cloud Elements Identification” phase (see Section 2.2.1 and (Alebrahim et al., 2014)). The central element for this step of the ClouDAT approach is the CloudElement. This can basically be anything of value to the company; from documentation to real physical systems. A cloud element is identified by a unique name und contains additional information such as type, owner, descriptions and a location. Additionally it can be excluded from the scope of the risk analysis once a convincing explanatory statement (rational) for this case is given.

CloudElements can be subject to requirements verbalized by stakeholders. The requirements are expressed using ClouDATs pre-defined RequirementPatterns illustrated in Figure 3. They consist of fixed text passages and generic text passages. Fixed text

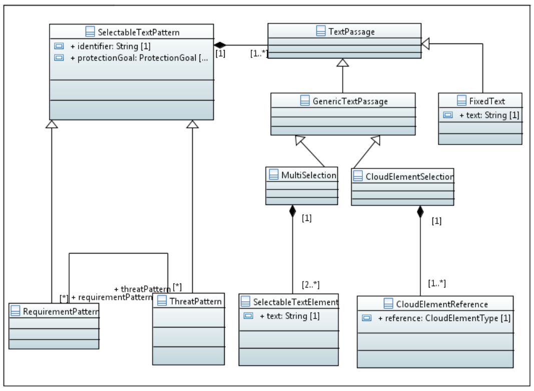


Figure 3: Selectable text metamodel.

passages represent the meaning of a security requirement and can not be edited by the user. Generic text passages can for example be multi selections or relations to specific cloud elements. The requirement patterns can be seen as clozes the user has to fill out in order to instantiate a certain requirement.

Figure 4 illustrates an example requirement. It consists of fixed text and multi selections. The elements in squared brackets represent the different options for a multi selection. Since Figure 3 provides a sufficient understanding of the concepts, Figure 2 does not show additional implementation detail for the instantiation of requirements based on requirement patterns, thus showing only the requirement class.

Requirements can be endangered by threats that

The cloud computing system shall ensure that a

[cloud customer, end customer, administrator]

only has the permissions of the assigned roles for

[cloud service]

Figure 4: An example of security requirement pattern.

are based on ThreatPatterns defined by the ClouDAT framework. The ThreatPatterns are shown in Figure 3 and are very similar to RequirementPatterns. Figure 5 shows an example for a threat pattern defined by ClouDAT. Since the threats indirectly endanger the CloudElements, there is also an association to it.

Disclosure of communication between the

[cloud service] and the

[cloud customer, end customer, administrator]

for example by network sniffing or gaining access to relevant areas.

Figure 5: An example of threat pattern.

The presence of threats entails risks. While threats are very abstract and by themselves propose no danger to a company, risks do. A risk represents the "potential that a given threat will exploit vulnerabilities of an asset or group of assets and thereby cause harm to the organization"(ISO, 2008). The risk class contains a description, which serves as unique identifier for a risk and a risk owner, which is the person responsible for a given risk. It is also possible, that a risk is accepted by the management without further treatment (acceptedMgmtApproval). This case however demands for a convincing explanatory statement (rationalMgmtApproval). Furthermore a risk consists of likelihoods, business impacts (assetValue) and the resulting risk levels for the protection goals confidentiality, integrity, availability and privacy. Since a certification requires every risk to be handled or accepted, it is mandatory to deliver an acceptance rule for every risk. The acceptance rule is called RiskMethod in ClouDAT, and contains a name, description and riskAcceptanceLevel. The acceptance level can be seen as a threshold not to be exceeded by risks using the RiskMethod.

The risks exceeding the acceptance level have to be treated by the user. Therefore ClouDAT allows the definition of RiskTreatments that consist of a treatment action and a justification that explains, why a certain action has been taken. ClouDAT allows to treat a risk by applying controls, accepting the risk, avoiding the risk or transfering the risk. In case a risk is treated by applying controls, the user has to specify the measures that were used to reduce the risk.

ClouDAT distinguishes between controls and measures. A control describes an action that can be taken to reduce a risk but is defined on a very abstract level, while a measure is a concrete implementation of a control. A control for example is "Asymmetric encryption" and a possible measure based on this control could be the implementation of a specific encryption protocol like RSA.

The class ControlPattern allows the definition of controls and consists of an id, name, description and indicators whether it is required by ISO27001 or it is an organizational or a technical control. Furthermore it is possible to provide example measures or an example for the control based on the IT-Grundschutz. Controls can also suggest the use of other controls or require the implementation of other controls. For example, the control "Password management system" requires the implementation of a "User registration and de-registration" system and suggests the "Use of secret authentication information". CloudDAT provides an extensive list of possible controls based on the ISO27001 (see Section 4).

A control can provide MeasurePatterns which can be seen as implementation possibilities for the given control. A MeasurePattern consists of a name, description and an indication whether the Measure is neccessary to implement the control or just a selectable implementation method. The concrete instantiation of a MeasurePattern is a Measure, that is associated with requirements and CloudElements.

# 4 RISK TREATMENT METHOD

As we mentioned in Section 2.2.5, our risk treatment method complies with the ISO 27001 and is specified with four different treatment methods, applying appropriate controls, accepting risks, avoiding risks, and transferring the associated business risks to other parties.

According to the ISO 27001 Sect. 6.1.3, considering the risk assessment results, an appropriate security risk treatment option must be selected. To this end, all the security controls that are necessary to the risk treatment must be determined. Afterwards, a comparison of the determined controls with those in the ISO 27001 must be performed, verifying that no mandatory controls have been excluded. Subsequently, a statement of applicability that incorporates the mandatory controls and explanations for inclusions and exclusions of the controls must be provided. In the following sections, we describe these steps in more details.

## 4.1 Security Controls

In order to apply appropriate controls, we need to specify a list of security controls, from which the proper security controls are selected to reduce the risks of the organization. "Controls include any process, policy, device, practice, or other action which modify risks" (ISO, 2014). The Annex A of the ISO 27001 standard provides the normative controls of the standard. Different international organizations have provided governance documents such as the NIST-SP800-53 (Nist and Aroms, 2012), the DISA Secure Application Security Technical Implementation Guide (STIG) (DISA, 2015), and the Cloud Security Alliance Cloud Control Matrix (CCM) (Cloud Security Alliance, 2014). In such documents, a set of security controls are collected. Likewise, in the course of ClouDAT project, we provide a control list. The control list contains:

- Security controls of ISO 27001 standard.
- Self-defined security controls: Security requirements have to be fulfilled by controls, hence to cover all security requirements we have defined a few security controls additionally.
- Security patterns: A security pattern, using some security mechanism, describes a solution to the problem of controlling a set of threats. We consider some of the security patterns, which are provided in (Fernandez-Buglioni, 2013), as security controls.

## 4.2 The Structure of the Control List

Figure 6 presents a snapshot of the control list. Due to the lack of space, we do not show the whole table. The control list is simply a table which contains all above mentioned security controls. For each control a set of aspects are defined. In the following, we describe these aspects.

- ID: The documented controls presented in control list are generally based on the security controls provided in annex A of ISO 27001, and sections 5 to 18 of ISO 27002 respectively. These controls are identified by the same ID as in the ISO documents. In the cases, which the standards do not provide appropriate controls, self-defined controls are provided, with the IDs beginning at 19.1 in order to avoid conflicts with the ISO controls.
- Control Text: A short title for the control. For ISO controls, the title matches the one in the original document. Self-defined controls are labeled similarly.
- Dependencies: This entry gives a list of other controls. Mainly two kinds of dependencies are defined:
  - Necessary: The other control should be implemented as well in the most cases. If the user chooses not to apply the necessary control, the reason must be justified.
  - Suggested: The other control might be useful to support the current control or its measure. The tool offers these controls as an option to the user.
- ISO 27001 - 2005 reference: The controls are based on the ISO revision of 2013. For the controls that have equivalent controls in the version 2005, the ID is given respectively.
- Security Requirement: List of relevant security requirements.
- Refinement of (ID): A reference to the control, which is refined by the provided control.
- Refined by (ID): A reference to the control, which refines the provided control.
- Protected Asset: List of the assets, which are protected by the provided control.
- Instance Type: The instance type of the control, when it is possible.
- Asset necessary to perform control with relevant security aspect: The implementation of a control can lead to the creation of additional assets, that need to be protected accordingly.
- BSI References: The related entries from the BSI Grundschutz catalogues.
- Also used in: List of similar controls from CCM (Cloud Control Matrix).
- Technology/Organization: Each control is classified whether it is primarily (+) or supportively (∼) technical or organizational.
- Description of control: A textual description of the control.

## 4.3 Risk Treatment Process

In Section 2.2.5, we described that after risk assessment, for the cloud elements with unaccepted risk level, appropriate security requirements are elicited. In the control list for each control a set of security requirements are specified. This mapping between controls and requirements simply indicates, which control fulfills which security requirement. Consequently, according to the elicited requirements, we can determine the necessary controls to reduce the

| ID (ISO 27002) | Control/Measure – Text (ISO 27002) | Dependencies | Req (Ausarbeitung) | Protected Cloud Element |
|---|---|---|---|---|
| A.5.1.2 | Review of the information security policy. | 5.1.1 necessary | - referenced indirectly from Security Management and others | generic |
| A.6.1.1 | Information security roles and responsibilities | A.9.2.3 necessary A.5.1.1 necessary | - referenced indirectly from Security Management and others | generic |
| A.6.1.2 | Segregation of duties | 5.1.1 necessary | Security Management 7 Security Management 15 | generic |
| A.6.1.3 | Contact with authorities | Necessary: A.6.1.3 | Security Management 18 | generic |
| A.6.1.4 | Contact with special interest groups | - | - referenced indirectly from Security Management | generic |
| A.6.1.5 | Information security in project management | Necessary: 25.4 | | generic |

Figure 6: A snapshot from the control list.

risks. In this process the dependencies between the controls are considered.

After the selection of the controls, we need to verify whether the risk levels of the cloud elements are reduced. To this end, we need to perform the risk assessment for particular cloud elements to check whether the controls reduce the risk levels or a modification of the controls or other controls are required. This process is iterated until there exists no cloud elements with an unaccepted risk level. However, sometimes we need to avoid or ignore the risk. Or alternatively, we need to transfer the risk to other parties. These decisions are manually made by the security analyzer and must be reasoned.

Furthermore, we need to provide a statement of applicability (compliant with Sect. 6.1.3 c-d of the ISO 27001). To this end, we have provided a template. This template is simply a table, in which for each selected control either must be justified why the control is excluded, or the overview of the implementation is provided, i.e. the necessary and suggested controls to perform the control are listed.

As an example for the risk treatment process, consider the case, in which the confidentiality of the personal data in a organization, for which we have have performed the risk analysis, is threaten. In Section 3, we have introduced the security requirement patterns. In our SRP catalog such a pattern exists:

"Confidentiality of personal data of [cloud customer, end customer] shall be achieved."

As we have already mentioned, a SRP has variable and fixed text passages. To instantiate the security requirement pattern, from the list of identified and refined cloud elements, an element as a representation of the cloud customer or end customer must be inserted into the variable text passage. Assume that the name of the Organization is *Organization A*, then the instantiated requirement is:

"Confidentiality of personal data of Organization A shall be achieved."

Using the provided mappings between security requirements and security controls in the control list, we select the relevant control:

"To address the security requirement, we apply the controls of the ISO 27001, e.g. access control policy (A.9.1.1), working in secure areas (A.11.1.5), network controls (A.13.1.1), including the controls that are specified as necessary to perform along with mentioned controls."

# 5 CARISMA, AN EXTERNAL SECURITY ANALYSIS TOOL

Along the risk assessment process, which is provided by the ClouDAT framework to certify cloud providers and generate documentation, the ClouDAT framework offers the functionality to analyze different cloud services and softwares with the help of external security analysis tools. For instance, consider the case, in which the cloud provider uses self developed cryptographic protocols instead of the standard protocols. In this case, an external tool for analyzing the protocols is needed. An appropriate external tool with different functionalities for security analysis is the CARiSMA tool framework. It offers different automatic verification plugins of UML diagrams for critical requirements. Generally, it provides automated analysis of UMLsec (Jürjens, 2005a) models for security requirements.

UMLsec is an extension of UML in form of an UML profile that provides model-driven development for secure information systems (Fernández-Medina et al., 2009). It can be used to express security requirements within UML diagrams (such as secure information flow (Jürjens, 2000)). Tags and stereotypes are used to express security requirements and assumptions on system environments. Moreover, constraints are used to determine whether requirements are satisfied by the system design UMLsec (Jürjens, 2005a).

The UMLsec approach has been used in a number of applications (Jürjens and Wimmel, 2001a; Jürjens and Wimmel, 2001b; Jürjens, 2001).

System security analysis using UMLsec requires an architectural analysis of the software system. To this end, all the components, objects, cloud elements, and the dependencies between them are needed.

In the case of a legacy system, these can be extracted from the code base using techniques for program comprehension such as (Ratiu et al., 2008).

In a certification process, it is possible to use different CARiSMA plugins as external tools for security analysis. For instance, we consider Control A.9.1.1 from ISO 27001 standard. It states, that an access control policy based on business and information security requirements must be established, documented, and reviewed (ISO, 2014). There exists different approaches to establish access controls. Generally, an access control method restricts the access to information and information processing facilities. If a cloud provider requires an external tool to control the access to information, the RABAC analyzer plugin of the CARiSMA can be used (CARiSMA, 2015). This plugin is based on the concept of Role Attribute Based Access Control (RABAC) (Jin et al., 2012), and is implemented and integrated to the ClouDAT framework for the access control analysis in cloud environments.

Above, we mentioned that a cloud provider may need an external tool to analyze cryptographic protocols. CARiSMA offers Sequence Diagram Crypto FOL-Analyzer (Jürjens, 2005b) for security analysis of cryptographic protocols. This plugin as an input receives a protocol, which is expressed as an UML sequence diagram, and performs the analysis.

The CARiSMA website (CARiSMA, 2015) provides more information about the different plugins for the security analysis.

# 6 CONCLUSIONS

The certification of cloud computing infrastructures is a very complex task for small and medium-sized enterprises. It requires a lot of effort to be taken because it is mandatory to do a detailed risk assessment and analysis and create detailed documentation of the efforts taken. ClouDAT provides a full fledged framework to support small and medium-sized enterprises in the cloud system certification process based on ISO27001. It consists of a detailed workflow on how to conduct the risk analysis and contains detailed lists of assets, requirements, threats, risks and controls to support the user during assesment phases. ClouDAT allows the user to analyse a modeled scenario both using integrated analysis methods and external analysis tools, thus exposing potential certification problems during analysis. Furthermore ClouDAT allows the automatic generation of ISO27001 compliant certification document, which helps the user in the certification process.

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# Establishing a Framework for Managing Interest in Technical Debt

Areti Ampatzoglou, Apostolos Ampatzoglou, Paris Avgeriou
*Department of Mathematics and Computer Science, University of Groningen, Netherlands*
*areti.ampatzoglou@rug.nl, a.ampatzoglou@rug.nl, paris@cs.rug.nl*

Alexander Chatzigeorgiou
*Department of Applied Informatics, University of Macedonia, Thessaloniki, Greece*
*achat@uom.gr*

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Abstract: Technical debt (TD) has gained significant attention over the past years. Due to its interdisciplinary nature, it has become attractive for both technical and management stakeholders, to acknowledge and discuss issues related to decayed design-time qualities over time, and their corresponding consequences. Until now, despite the inherent relevance of technical debt management to economics, the TD research community has not sufficiently exploited economical methods/models. Therefore, in this paper we present a framework for managing interest in technical debt, founded on top of well-known economic theories (i.e., Loanable Funds and Liquidity Preference Theory) and current TD research. Specifically, in our framework, we will discuss aspects related to technical debt interest, such as: types of TD interest, TD interest characteristics, and a proposed TD interest theory. Finally, in order to boost the amount of empirical studies in TD research, we will propose several tentative research designs that could be used for exploring the notion of interest in technical debt practice.

## 1 INTRODUCTION

The term *Technical Debt* (TD) was coined in 1992 by Ward Cunningham (1992) to describe the technical compromises being made while coding, in order to speed up product delivery and meet release deadlines. Research on technical debt is rapidly growing over the last years, since around 90% of articles on the subject have been published after 2010 (Li et al., 2015). Similarly to its success among academics, TD seems to be a topic that is appealing for practitioners, as well. Specifically, according to Li et al. (2015), from the current corpus of research efforts in technical debt, 43% is performed in academia, 40% in industry and 17% in both.

Apart from the fact that TD is a problem of paramount importance for software development, another possible explanation for its popularity, in both academia and industry, is its interdisciplinary nature (software engineering and economics), which facilitates the communication among technical and management stakeholders (Ampatzoglou et al., 2015). To achieve this, the TD community *borrows* terms from economics and maps them to software engineering ones. Based on two recent literature reviews on the subject (Ampatzoglou et al., 2015 and Li et al., 2015), the two most frequently used financial terms in TD research are: *interest* and *principal*.

Principal is a clearly defined concept, which is characterized as the effort required to address the difference between the current and the optimal level of design-time quality, in an immature software artefact or the complete software system (Ampatzoglou et al., 2015). Therefore, it is quantifiable and, in general, a commonly accepted concept. On the other hand, interest (associated with many definitions, which in some cases are controversial) cannot be measured in a straightforward way, since it involves the valuation of future maintenance activities. Measuring interest becomes even more complicated due to the fact that its occurrence is not certain, in the sense that extra cost/effort might not be required, and therefore interest will not need to be paid off.

Additionally, research on TD interest and TD in general, appears to lack empirical evidence. According to Li et al. (2015) 49% of the complete corpus of TD research presents no empirical evidence, or only toy examples, whereas this number rises to 56%, when focusing on interest (Li et al., 2015).

To partially alleviate these problems, in this study we investigate the notion of interest as it is applied in the TD domain; our goal is to propose FItTeD, i.e., a Framework for managing Interest in Technical Debt. The FItTeD framework, aims to:

(***G1***) Identify types of TD interest, when it occurs, and the high-level structure of its calculation. Identifying the types of interest, which can occur along evolution, is the first step towards more formal Technical Debt Management (TDM). Until now, the definitions of interest are rather high-level, and interest measurement is often not applied in practice.

(***G2***) Explore how various characteristics of interest in economics apply in TD interest. An example of such a characteristic is whether interest is simple or compound. However, these characteristics have not been fully exploited in research state-of-the-art, yet.

(***G3***) Propose a TD interest theory. Until now, no study has used the economic interest theories for modelling technical debt interest. We will rely on the Liquidity Preference Theory, for modelling the evolution of TD.

The cornerstones for the development of FItTeD are:

- ***The corpus of existing research on Technical Debt Management (TDM)***. We intend to reuse the primary studies identified in a Systematic Literature Review (SLR) on technical debt by Ampatzoglou et al. (2015), and filter them so as to extract primary studies related to interest, and synthesize them in a systematic way (Kitchenham et al., 2009).
- ***The existing economic interest theories***. We intend to apply existing economic interest theories, i.e., the *Loanable Funds* and the *Liquidity Preference Theory*, to reuse existing knowledge from economics, on how interest should be handled, and learn from accumulated experiences.

This framework aims at supporting software engineers to determine the change of technical debt amount in the future, by holistically describing all parameters that affect its future value (i.e., repayment, interest, additional debt, etc.). This can in turn allow the use of elaborate financial methods in several technical debt management activities, i.e., repayment, monitoring, and prioritization. Additionally, we expect that the proposed framework can boost empirical research in the field of TD, in the sense that it can facilitate a common understanding on TD interest and point to interesting research directions.

The rest of the paper is organized as follows: In Section 2, we present related work from the field of economics, i.e., the dominant interest theories. Next, in Section 3, we will present the outcome of revisiting the primary studies of the SLR by Ampatzoglou et al. (2015), by presenting only interest-related information. In Section 4, we present the proposed framework for managing interest in technical debt. In Section 5, we discuss possible ways that our framework can be used for boosting empirical research in the field of TD. Finally, in Sections 6 and 7, threats to validity and conclusions are presented.

## 2 INTEREST IN ECONOMICS

Regarding the way interest rate is defined in the market; various models have been suggested, by different schools of economics (Mishkin and Eakins, 2012). The mainstream theories are the *Loanable Funds Theory*, developed by the neoclassical school, and the *Liquidity Preference Theory*, proposed by the Keynesian theory (Mishkin and Eakins, 2012).

Interest rate is the price paid for borrowing money or vice versa (the payment received to loan money). Therefore it can be considered as the price of money. Interest rate, as any other price, can be defined in the market at the equilibrium between supply and demand. According to the Loanable Funds Theory, interest rate specification takes place in the market of loanable funds. On the one hand, individuals or enterprises, who want to invest, form the demand for loanable funds. They ask for loans in order to proceed with an investment. As interest rate gets higher, borrowing becomes more expensive. As a result, demand for loanable funds decreases as interest rate increases. On the other hand, the supply of loanable funds comes from people or enterprises that use the loanable funds market to save their money. Instead of consuming part of their income, they choose to put it into the loanable funds market in order to save it for later. In this case, higher interest rate means higher return on savings. Therefore, supply of loanable funds rises as interest rate increases.

In the diagram of Figure 1, the equilibrium in loanable funds market is presented. We note that, in economic theory, all kinds of supply – demand diagrams represent the dependent variable on the horizontal axis and the independent variable on the vertical axis. Therefore, in this case, the vertical axis depicts interest rate ($r$), while the horizontal axis represents the quantities of supply and demand for loanable funds. The quantity of loanable funds supplied at any level of interest rate is presented by line $S$. Line

S depicts the positive correlation between interest rate and loanable funds supply. Likewise, the quantity of loanable funds demanded at any level of interest rate is presented by line *I*. The negative correlation between interest rate and loanable funds demand is indicated by the negative slope of line I. When interest rate is higher than *r**, then it is more profitable to save, or it is more profitable to lend than to borrow, and supply of loanable funds is higher than demand. On the other hand, when interest rate *r* is lower than the level of r*, then it is more profitable to invest, or it is more profitable to borrow than to lend, and demand for loanable funds is higher than supply. When r=r*, then both the investors and the savers have no motivation to change their position in the market and equilibrium is achieved. Consequently, interest rate is determined at r=r*.

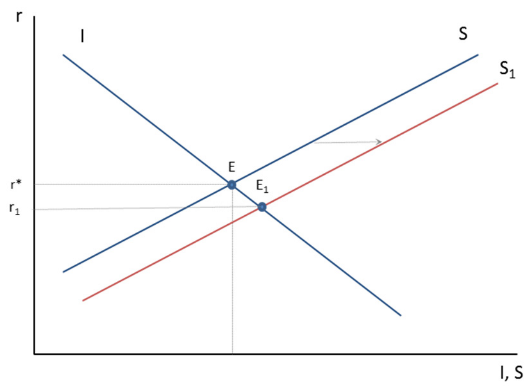


Figure 1: Loanable Funds Theory.

Equilibrium in the market is achieved at interest rate r*, when every other factor, that could influence savings or investment, is considered stable (ceteris paribus – i.e., a Latin phrase, often used in economics to suggest that all other factors are constant, in order to examine the relationship between two variables). Therefore, interest rate level may move upwards or downwards in case of changes to savings or investments, due to exogenous factors (e.g., income). For example, an increase in income would cause an increase in the quantity of savings. That would result in a shift to the right of the savings curve (S), which is the supply of loanable funds. In Figure 1, the new line $S_1$ depicts such a change. As shown in the diagram, the new equilibrium is now achieved at point $E_1$ and interest rate is defined at $r_1$, lower than r*.

The Liquidity Preference Theory determines interest rate level through the mechanism of supply and demand for money (cash), which is performed in the money market. In this case, supply of money (M) is given at any point of time and is determined by the central bank, according to the needs of the economy. In other words, supply of money is not dependent on interest rate and it is exogenously defined. On the other side, demand for money (L) represents the quantity of cash that people prefer to hold for purposes of transactions, precaution or speculation. In this case, as interest rate increases, it becomes more profitable for people to invest money than to hold it. Consequently, an increase in interest rate leads to a decrease in the quantity of money demanded in the market and a decrease in interest rate causes an increase in demand for money. Similarly to the Loanable Funds theory, interest rate is determined by the equilibrium point of the market.

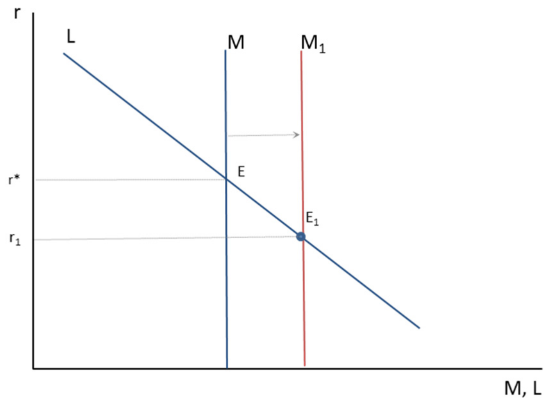


Figure 2: Liquidity Preference Theory.

The diagram of Figure 2 shows the equilibrium in the market of money. Interest rate is represented on the vertical axis, whereas money supply and demand are shown on the horizontal axis. The supply curve is vertical to the horizontal axis, and represents the stable money supply, provided by the central bank, independently of the interest rate level, as mentioned above (this assumption consists the main difference with the loanable funds theory). Demand for money is negatively related to interest rate (because in this case interest rate is the cost of holding money against to investing in a bond) and line *L* shows the quantity of money demanded at any given interest rate, ceteris paribus. The intersection of the two curves, *M* and *L*, represents market equilibrium and determines the level of the interest rate at *r**.

In case of a change in demand for money because of a change in another determining factor, e.g. income, or in case of a change in the quantity of money supplied by the central bank, equilibrium rate will change. For example, if the central bank decides to increase money supply, then M would increase to $M_1$ and the curve in the diagram of Figure 2 would shift to the right. Consequently, equilibrium would be defined by point $E_1$ and the new interest rate in the market would be $r_1$, lower than r*.

# 3 INTEREST IN TECHNICAL DEBT RESEARCH

In this section we present an overview of studies that have investigated interest in Technical Debt Management (TDM). According to Ampatzoglou et al. (2015) and Li et al. (2015), interest is the prominent financial term that is used in TDM research. Note that in economics, interest theories are used for calculating interest rate (not interest per se), since interest is calculated based on interest rate. However, in TDM interest is not calculated based on interest rate, but it is assessed in various other ways, as explained later in this section. Specifically, from TD research, it is not clear if interest rate can be defined at all. In this study, we reuse the dataset extracted by Ampatzoglou et al. (2015), i.e., *29 studies that focus on TD interest*. In this paper, we are not presenting in detail the SLR process, since it is thoroughly discussed in the original study, but only an outline:

- Queried 7 digital libraries (IEEE, ACM, Scopus, Springer, Science Direct, Web of Science, and Google Scholar), with the term *technical debt*. The search returned 1,173 primary studies
- Applied Inclusion/Exclusion Criteria (e.g., is the study focused on the financial aspect of TD). The process returned 69 primary studies.

From that stage and on, the process is specialized to the goals of this paper. Specifically, first we filtered primary studies related to interest. This step has been performed as part of data collection in the original SLR. Therefore, in this study we explored the 29 primary studies, which according to Ampatzoglou et al. (2015) are relevant to interest. This set of studies is our primary study dataset. For each study, the following data have been extracted:

[***$D_1$***] *Interest amount definition*. We record the definition that the authors provide for the amount of interest. The term interest amount is derived by the work of Seaman and Guo (2011), who suggest that interest should be calculated by taking into account two components *interest amount* and *interest probability* (see D2).

[***$D_2$***] *Interest probability definition*. We record how interest probability is defined and calculated.

[***$D_3$***] *Evolution of Interest*. We record any possible discussion that is related to how TD interest amount grows or shrinks, along evolution. For example, we capture if a study characterizes interest as compound or simple, or as continuously increasing.

[***$D_4$***] *Interest estimation method*. We describe how TD interest is quantified in the primary study (when applicable).

The mapping between data extracted and the goals set in Section 1, are discussed below:

***G1***: We use [***$D_1$***] and [***$D_2$***]. Based on the frequency of each variable, we extract the most common definitions of *interest amount* and *interest probability*.

***G2***: We use [***$D_3$***] that is related to studies, which discuss the evolution of technical debt interest. Based on existing literature, and the definitions derived from G1, we formulate the evolution of TD interest, and investigate cases when it is increasing or decreasing.

***G3***: We use [***$D_4$***] that aims at describing how each study assesses the amount of interest or the interest probability, and synthesize them with the financial interest theories and the definitions derived from G1, to develop an interest theory that is applicable for TD.

The outcome of the data collection phase is presented in Table 1 and Table 2. Specifically, in Table 1, we present data *$D_1$ and $D_2$*; whereas in Table 2, we present data *$D_3$* and *$D_4$*. We note that due to space limitations: (a) in both tables, the citation is provided with limited identifiers needed for characterizing a study (e.g., omitting "et al."), and (b) in Table 2, we only present studies that hold a value for at least one variable.

From Table 1, we can observe that about 31% of primary studies describe ***interest amount*** as the extra effort during maintenance, whereas 51% as the extra maintenance cost. However, since in software economics cost is usually defined as a function of effort, we can assume that 82% of studies refer to *interest amount as the extra effort/cost that is evident during maintenance activities, due to the presence of technical debt*. The rest of the studies, either provide more high-level definitions – i.e., (Eisenberg, 2012) and (Letouzey, 2012) – or define technical debt interest, similarly to economics, i.e., the increase rate of technical debt amount (Ernst, 2012), or define interest as a change in a design-time quality attribute – see for example (Seaman et al., 2012) and (Zazworka et al., 2011). Additionally, we can observe that approximately 28% of the studies acknowledge the existence of ***interest probability***. From these studies, two – i.e., (Guo and Seaman, 2012) and (Snipes, 2012) – adopt a financial risk management approach where interest probability is calculated as *the standard deviation of interest rate*; whereas the rest adopt a risk management approach, i.e., they *consider interest probability as the probability of the TD incurring event to occur*.

Table 1: Data Extraction Overview. (1/2).

| Study | Interest Amount | Interest Probability |
|---|---|---|
| Allman (2012) | *Increased effort* to maintain and extend the system | |
| Alzaghoul (2013) | *Cost incurred by time* due to an investment at service level which is not properly managed | |
| Brown (2010) | *Increased future costs* owing to earlier quick and dirty design and implementation choices | The *probability* that a particular type of TD will have visible consequences |
| Buschman (2011) | *Cost to be paid later* due to quick development | |
| Chin (2010) | *Cost of organization* to hold on TD, plus the additionally incurred debt | |
| Codabux (2013) | *Additional cost* of not eliminating TD now | |
| Curtis (2012, Software) | *Continuing costs* attributable to should-fix violations that haven't been remediated | |
| Curtis (2012, MTD) | *Continuing costs* attributable to should-fix violations that haven't been remediated | |
| Eisenberg (2012) | *Long-term impact* of TD | |
| Ernst (2012) | The *rate of increase* in TD | |
| Falessi (2013) | The *cost that will occur* by not fixing the technical problem | Interest is not certain. It has a *probability* to occur, changing over time |
| de Groot (2012) | The *difference in cost* between maintenance at the ideal level and any level below | |
| Guo and Seaman (2011) | *Extra work* that will be needed if TD item is not repaid | *Interest standard* deviation, because of the uncertainty of interest |
| Guo et al. (2011) | *Additional cost* | |
| Holvitie (2013) | The amount of *extra work* the principal can cause to future development | The *probability* of extra work TD can cause to future development |
| Koolmanojwong (2013) | *More expensive to fix* than it is to do it right the first time | |
| Letouzey (2012) | The *negative impact* of TD | |
| Marinescu (2012) | *Extra maintenance effort* required in the future due to hasty, inappropriate design | |
| McGregor (2012) | Any *extra work* over the expected amount, when later we carry out the deferred activity | |
| Nord (2012) | *Increasing rework* cost of the unpaid TD | |
| Nugroho (2011) | The *extra maintenance cost* spent for not achieving the ideal quality level | |
| Schmid (2013) | *Additional effort* spent on not quite good code | |
| Seaman (2011) | *Potential penalty* paid in the future as a result of not completing tasks in the present | The *probability* that TD, if not repaid, will make other work more expensive |
| Seaman (2012) | *Decreasing maintainability* | The *probability* that TD, if not repaid, will make other work more expensive |
| Siebra (2012) | *Extra Effort* | |
| Snipes (2012) | The *extra cost* required to complete a maintenance activity in the future if the task is postponed, plus the cost of other work that is required due to the presence of the TD | Interest *standard deviation*, because of the uncertainty of interest |

| Study | Interest Amount | Interest Probability |
|---|---|---|
| Zazworka (2011) | *Impact on quality* | |
| Zazworka (2013) | An estimate of the amount of *extra work* that will be needed if this TD item is not repaid | The *probability* that TD, if not repaid, will make other work more expensive |
| Zazworka (2014) | Probable *future cost* of not fixing the TD | |

Table 2: Data Extraction Overview. (2/2).

| Study | Interest Evolution | Estimation Method |
|---|---|---|
| *Allman (2012)* | Compound | - |
| *Buschman (2011)* | Compound | - |
| *Chin (2010)* | Both | - |
| *Codabux (2013)* | Increasing | - |
| *Guo and Seaman (2011)* | | Expected interest amount and interest standard deviation can be estimated using historical effort, usage, change, and defect data. |
| *Guo et al. (2011)* | | Interest = interest amount × interest probability<br>IA = X – P,<br>X: Cost of doing something at $t_2$ (after postponing at $t_1$), P: principal |
| *Nord (2012)* | Increasing | - |
| *Nugroho (2011)* | | interest would be the difference between maintenance effort spent at the 5-star level and any of the lower quality levels<br>ME = MF*RV/QF<br>MF=Maintenance Fraction (Historical Data), QF=Quality Factor, RV=Rebuild Value (estimate of effort to be spent to rebuild a system) |
| *Seaman (2011)* | | Interest amount = W × C, C=average cost of the last N modifications to module, W=weighting factor , based on the initial rough estimate (high, medium, or low) of the interest amount |
| *Siebra (2012)* | Increasing | Estimation based on documentation (chronograms, backlogs and code lines modifications) as the total effort between alternative scenarios |

Furthermore, the results of Table 2, suggest that approximately 21% of primary studies deal with the evolution of interest along time and either characterize it as compound, or continuously increasing. As an exception to this, Chin et al. (2010), proposes that one type of interest is simple. Specifically, they suggest that the cost of the organization to hold on TD is stable across time and neither increases nor decreases.

Finally, only 17% of studies propose a specific way of measuring interest. The estimation is in most of the cases performed by using historical data, documentation, and maintenance effort estimation models (for details see Table 2).

# 4 FRAMEWORK FOR MANAGING INTEREST IN TD

In this section we present FItTeD, i.e., the proposed framework for managing interest in technical debt. While presenting FItTeD, the discussion focuses on goals ***G1*** – ***G3***, as set in Section 1. The proposed framework is based on the findings discussed in Section 3 and on the general perception of interest as the extra effort required for performing any maintenance tasks when technical debt has been accumulated. However, it has been enhanced, by our own suggestions to cover gaps in the current literature.

### 4.1 Types of Interest

From the technical debt literature it is evident that technical debt interest is perceived as a risk for software development, in the sense that it has a specific effect (i.e., *interest amount*) and a probability to occur (i.e., *interest probability*). Concerning the amount of interest, we assume that interest can be accumulated through the extra cost incurred by two activities:

- ***Interest while repaying TD – I(r)***: The effort for repaying technical debt at any time point $t$ (i.e., enhancing the quality of a Technical Debt Item - TDI) is higher than the effort needed for repaying technical debt for this item, at any time point prior to $t$. Therefore, $I(r)$ is calculated as the difference between the two aforementioned efforts. This type of interest will occur when (and if) the amount of TD is to be paid off.
- ***Interest while performing maintenance activities – I(m)***: Performing maintenance tasks is more time/effort consuming in parts of the software with accumulated TD, compared to parts in which TD is reduced or zero. The difference between the two amounts of effort is the amount of the $I(m)$ interest. This type of interest will occur, and will be simultaneously repaid, when maintenance tasks are performed (i.e., while undertaking the effort to perform the maintenance task).

Both the aforementioned types of interest are in agreement with the most established definitions of interest amount (i.e., extra cost/effort); however by adding more details on when these extra costs/efforts can occur. Thus, for each technical debt item, interest ($I_{TDI}$) should be calculated, based on the following high-level formula:

$$I_{TDI} = I(r) + I(m) =$$
$$= P(r) * E(r) + P(m) * E(m),$$

in which $P$ denotes the probability of a repayment or maintenance event to occur, $E$ the effort needed to perform an action, $r$ denotes repayment, and $m$ other maintenance activities. To transform the aforementioned formula from the TDI level to the system-level, we propose the use of the sum aggregation function, in the sense that the total TD of a system is the sum of TD, of all items with incurred TD. Therefore, interest at system level ($I$) can be calculated, as follows:

$$I = \sum_{j=0}^{j=count\,(TDI)} P(r_j) * E(r_j) + P(m_j) * E(m_j)$$

We note that the aforementioned formulas cannot be used per se, but should be instantiated from researchers, by conducting empirical research that would assign estimates for the $P$ and $E$ factors. For examples and interesting research directions on this issue, see Section 5.

### 4.2 Evolution of Interest

Based on economics, interest is classified over two dimensions: its method of calculation and its variation over time. For these purposes, interest can be:

- ***Simple*** or ***Compound***: Interest is simple when it is calculated only as a function of the principal; whereas it is compound when it is calculated over the principal, plus the incurred interest; and
- ***Fixed*** or ***Floating***: Interest rate is fixed, if it does not change along time; whereas it is floating when it can increase or decrease based on circumstances.

Technical debt literature has discussed these characteristics of interest, but only superficially, without empirical evidence on the real-world evolution of interest. As already explained in Section 1, interest rate is not defined in technical debt. Therefore, the distinction between floating and fixed interest rates is not applicable. However, interest amount can still increase or decrease, based on the amount of debt that it is calculated upon. To this end, we note that studies which refer to *continuously increasing interest* are referring to debt amount and not interest amount.

From observing the literature, we can claim that researchers perceive technical debt interest as *compound*, in the sense that it is increasing, since the additional effort to repay technical debt and perform maintenance on a technical debt item increases as software grows. At any specific point in time ($t_1$), it is non-trivial to decompose the complexity of the system to the original system complexity ($C_o$), i.e., the one that existed in the system when the principal incurred, and the additional system complexity ($C_A$), i.e., the one that incurred due to system evolution (system larger in size, more functionality, etc.). Therefore, the calculation of the effort needed to perform any maintenance action in $t_1$, can only be assessed based on system current complexity ($C_c$).

However, interest is not expected to be continuously increasing. We expect that such a claim only holds for cases when no repayment activities are performed. Specifically, in case that some repayment activity is performed (at $t_0$), we expect system complexity after partial repayment ($C_R$) to decrease (i.e., $C_R < C_c$), leading to a decreased amount of both types of interest, in future maintenance activities - $E(r|m)$.

These claims are valid for individual TDIs, in which no additional technical debt has been incurred between timestamps $t_0$ and $t_1$; and summarized as follows:

$$I_{\text{Evolution}} \begin{cases} E(r|m_{t1}) > E(r|m_{t0}),\ E(r_{t0}) = 0 \\ E(r|m_{t1}) > E(r|m_{t0}),\ E(r_{t0}) < I_{t0} \\ E(r|m_{t1}) < E(r|m_{t0}),\ E(r_{t0}) > I_{t0} \end{cases}$$

For example (2nd clause): in case the effort spent at time point $t_0$ to partially repay technical debt $E(r_{t0})$ is lower than the additional interest incurred at $t_0$ $I_{t0}$ then it is reasonable to assume that any future maintenance or repayment effort $E(r|m_{t1})$ will be higher than the corresponding effort required at $t_0$ $E(r|m_{t0})$, in the sense that the amount of debt (diminished design-time quality or complexity) is larger at $t_0$ compared to $t_1$.

## 4.3 Interest Theory

Based on the above, and by borrowing the rationale of the equilibrium achievement from the existing economic interest theories, we have been able to develop an interest theory for managing TD interest. Specifically, we adopt the concept of the *Liquidity Preference Theory*. The reason for selecting the *Liquidity Preference Theory* and not the *Loanable Funds Theory* is that in TD the amount of money that is available to the company for managing technical debt is stable, i.e., the amount that has been saved, while incurring TD – i.e., the principal (supposing that principal is not invested, to provide extra benefits). The assumption that the available money for managing TD is principal, is based on the fact that principal is the maximum amount that can be spent without spending any additional effort (other than the one saved).

In the proposed interest theory, we map ***money supply*** to ***principal***, in the sense that principal is the amount of money that is available to the software development company, after incurring TD; and the ***money demand*** to the ***accumulated amount of interest***, in the sense that this is the extra amount of money that is demanded by the company when perform future maintenance activities, caused by the TD. In Figure 3, where we present the FItTeD Interest Theory, the ***x-axis*** represents ***time***, whereas the ***y-axis*** represents ***amount of money***. Therefore, the equilibrium point ($E_0$) denotes the time stamp ($t_0$), in which the company has spent the complete amount of money from the internal loan (i.e., initial principal – $P_0$) in extra maintenance activities because of the incurred TD.

We note that the specification of the equilibrium point is achieved through an analysis based only on effort, i.e., the effort saved when taking on TD and the extra effort required for any future maintenance activity because of its accumulation. Any other related costs or benefits related to technical debt occurrence (e.g. gains from launching the product earlier) have been excluded from the model for simplicity reasons. Thus, if the expected lifespan of the specific TDI is shorter than $t_0$ then undertaking technical debt is a beneficial choice, whereas if not, technical debt becomes harmful for the company. The aforementioned discussions, in the case that no repayment actions are performed, are summarized in the blue lines of Figure 3.

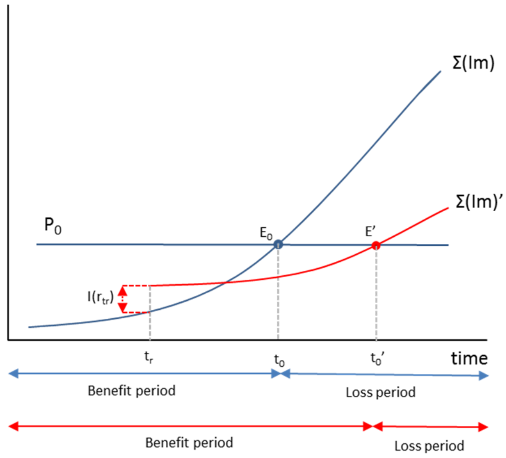


Figure 3: FItTeD Interest Theory.

Additionally, in Figure 3, we consider $\Sigma(Im)$ as *continuously increasing*, since it is a sum of positive numbers and as *exponentially increasing*, because TD interest is compound (see Section 4.2). In case that some repayment occurs at some timestamp ($t_r$), the line of the accumulated interest $\Sigma(Im)$ is moved upwards, due to the interest paid for repayment – i.e., $I(r_{tr})$ – but its slope is decreasing, since the interest is expected to lower for future maintenance activities ($Im$). This in turn leads to a shift of the equilibrium point ($E'$) to the right, increasing the benefit period ($t_0'$). The fact that principal is lowered to $P_{tr}$ ($P_{tr} < P_0$), is not presented in the diagram since the money supply line ($P_0$) is not moved, because the originally available budget of the company is not affected. The proposed interest theory can help practitioners in their decision making by:

- Identifying the timestamp in which incurring TD, becomes harmful for the company. Thus, they can decide if they should undertake the debt.

- Supporting them on continuously monitoring the interest that they have paid so far.
- Evaluating the repayment activity, based on the time-shift of the equilibrium point that it offers.

# 5 RESEARCH IMPLICATIONS

As already discussed in Section 3 research on TD interest is very theoretical and lacks empirical evidence. Therefore, in this paper we aim at pointing out specific research directions, which would boost the empirical research related to TD. The results of these empirical studies would provide data for the instantiation of the FItTeD interest theory. We organize the tentative research design by goal:

***Types of Interest***: An interesting research direction could be the empirical investigation of:

- whether $I(r)$ and $I(m)$ occur with the same frequency, and
- whether $I(r)$ and $I(m)$ produce a similar amount of interest when they occur,
- how $I(r)$ and $I(m)$ amount could be modelled, as a function of the principal, or the underlying structure of the TDI.

So far, these questions have been explored only by Guo et al. (2011), Nugroho et al. (2011), and Siebra et al. (2012), by exploring historical changes and documentation. The research state-of-the-art lacks real-world evidence on effort allocation.

***Evolution of Interest***: A possible empirical investigation of the evolution of TD interest could reveal interesting characteristics of TD, such as:

- What is the relationship of the decay of quality in the underlying system structure and the increase in $E(m)$ or $E(r)$? Answering this question could guide practitioners on how to model the increase of interest during software evolution.
- How frequently is $E(r_{t0})$ higher or lower than $I(r_{t0})$? Answering this question could unveil the frequency with which repayment activities can constitute interest increasing or decreasing.

***FItTeD Interest Theory***: In order to increase the applicability of the proposed TD interest theory, the following questions need to be empirically explored:

- What is the average time-shift that is benefited from performing specific repayment activities?
- From what factors is this time-shift influenced?
- What is the relationship between $I(r)$ and the average decrease in the $I(m)$ of future maintenance activities?

Answering these questions, would enable practitioners to instantiate the proposed interest theory, based on real and context-specific data, and transform FItTeD into a useful tools for practitioners.

# 6 THREATS TO VALIDITY

In this study, we actually inherit all threats to validity from the original SLR on which we have based our results upon (Ampatzoglou et al., 2015):

- the identification of primary studies
- the generalization of results, and
- the conclusions

Concerning data extraction, since we independently performed this step, the corresponding threats are related only to this study. To mitigate bias, while extracting data, two researchers performed data collection independently, compared the results and discussed possible differences. The final dataset was built through the consent of all authors. Finally, as a threat we acknowledge that the construction of the presented formulas, is to some extent based on the understanding of the authors on TD interest.

# 7 CONCLUSIONS

Nowadays, Technical Debt (TD) is receiving increasing interest by both academia and practitioners, leading to an explosion of studies in this field. The cornerstones of TD are two notions borrowed from economics: i.e., *principal* and *interest*. Although principal is a well-established term, interest has so far been discussed in a rather coarse-grained way, with several contradictions among researchers.

In this paper, we propose *FItTeD*, i.e., a framework for managing interest in TD, which takes into account existing TD literature and economic interest theories. The framework comprise of: (a) a TD interest definition, (b) a classification of TD interest types, (c) a characterization of TD interest evolution, and (d) a TD interest theory, based on the Liquidity Preference Theory. The proposed framework is expected to aid in the decision making of practitioners, and points to interesting research directions. The main emphasis of the future research directions is on empirical studies, which until now are underrepresented in the TD research corpus.

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# Extending the Business Model Canvas: A Dynamic Perspective

Boris Fritscher[1] and Yves Pigneur[2]
[1]*HEG-Arc, HES-SO // University of Applied Sciences Western Switzerland, 2000 Neuchâtel, Switzerland*
[2]*Faculty of Business and Economics, University of Lausanne, 1015 Lausanne, Switzerland*
*boris.fritscher@he-arc.ch, yves.pigneur@unil.ch*

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Abstract: When designing and assessing a business model, a more visual and practical ontology and framework is necessary. We show how an academic theory such as Business Model Ontology has evolved into the Business Model Canvas (BMC) that is used by practitioners around the world today. We draw lessons from usage and define three maturity level. We propose new concepts to help design the dynamic aspect of a business model. On the first level, the BMC supports novice users as they elicit their models; it also helps novices to build coherent models. On the second level, the BMC allows expert users to evaluate the interaction of business model elements by outlining the key threads in the business models' story. On the third level, master users are empowered to create multiple versions of their business models, allowing them to evaluate alternatives and retain the history of the business model's evolution. These new concepts for the BMC which can be supported by Computer-Aided Design tools provide a clearer picture of the business model as a strategic planning tool and are the basis for further research.

## 1 INTRODUCTION

Competition for companies and start-ups has evolved in the past decade. Today, success cannot be achieved on product innovation alone. At a strategy level, having the means to improve the design of business models has become a real issue for entrepreneurs and executives alike. Business models methods are a good way to share a common language about part of a strategy across a multidisciplinary team. These methods enable quick communication, and help improve the design of a new business model, as well as assess existing ones.

There are many different business model ontologies which focus, for example, on economics, process, or value exchange between companies. One such business model tool which is getting popular is the Business Model Canvas (BMC) (Osterwalder & Pigneur, 2010). Its visual representation and simple common language are two essential characteristics which have helped spread its adoption and make its book a bestseller. The current version of the BMC is an evolution from the original academic work the Business Model Ontology (BMO) (Osterwalder, 2004). The need to evolve the model took place to better fit the needs of practitioners over academics. The visual representation was improved under the influence of design thinking practice.

Through observation gained from, giving workshops, teaching to students and a survey, it appears that the building blocks of the BMC are covering the main needs, however usage itself of the model seems very basic and is limited to static analysis of one business model at a given time. This can be linked back to its original ontology which is used to describe a static model.

In reality, companies have to change and adapt to internal and external changes which impact their business. Therefore, a business model method should also consider the dynamic nature of transformation and evolution of the model.

This brings us to the following research question:

**How to represent and help to design the dynamic aspect of a business model with the Business Model Canvas?**

Before answering the question we provide a detailed history of the transformation of the BMC and provide some lessons learned for business model designers. Then in order to answer the question we first contribute to a definition of the maturity level of BMC users. Based on the three identified levels: novice, experts and master, we split the main question into three sub questions. For each, we contribute to a concept on how to handle a particular dynamic aspect.

On the first level, the BMC supports novice users as they elicit their models; it also helps novices to build coherent models. On the second level, the BMC allows expert users to evaluate the interaction of business model elements by outlining the key threads in the business models' story. On the third level, master users are empowered to create multiple versions of their business models, allowing them to evaluate alternatives and retain the history of the business model's evolution.

We adopted the following design science structure for our paper: After this introduction, we present the prior work on the business model canvas with a focus on its origin, evolution and adoption. Followed by a short presentation of the methodology and how we address the research question in multiple parts. The main artifact section presents two new concepts: business model mechanics and business model evolution, to help address designing the dynamic aspect of a business model. In the evaluation section we present the validity of the concept. We end the paper with a discussion and a conclusion on the implications for future research in business model design.

# 2 PRIOR WORK

In this section we present the origin of the business model canvas and how it evolved through the years influenced by its adoption. Business model ontology has evolved since its initial design. Retrospectively, we can distinguish there distinct stages: 1) the creation of Business Model Ontology (BMO), 2) followed by its first confrontation with reality, 3) which then paved the way for its design-influenced redevelopment.

## 2.1 Business Model Languages

Whilst many other business model languages exist, this paper does not include a detailed comparison of them. We have, however, sought to highlight the differences between Business Model Ontology (BMO) and its closest alternatives. Starting around the same time as BMO, e3-value (Gordijn & Akkermans, 2001) includes many similar concepts, many of which can be mapped between them (Gordijn, Osterwalder, & Pigneur, 2005). In particular, e3-value goes into more detail about the interactions between the components. In addition, it specifies the value which is exchanged in both directions and the way in which it flows. Using e3-value, it is possible to go beyond creating a single business model; indeed, it is also possible to model the interactions between business models within a sector. This detailed modeling of interactions comes with the necessity to specify ports through which the connections flow. Consequently, this makes visual representation more complex. The relationship between elements can further be described with types and values that allow for the basic financial calculation of the model.

Whilst BMO is concerned with providing a small but complete set of strategic components to describe a business model, another modeling language, known as SEAM (Wegmann, 2003) also exists. SEAM focuses on enterprise architecture and addresses the issue by providing a hierarchical decomposition. It uses a visual representation to handle the encapsulation of its hierarchies, which allows an exploration of the underlying resources and processes that contribute to the high level element. In the past few years, SEAM (Golnam, Ritala, Viswanathan, & Wegmann, 2012) and BMO (Osterwalder, 2012) have both evolved ways to better describe and explore the connection between the value proposition and customer segments. An essential part of both models is to be able to visually display the elements and show their connections at the same level as the concepts. The visual handling of encapsulation does, however, generate complex diagrams, which can be hard to read for the non-initiated.

Weill and Vitale (2001) illustrated a method for the schematic description of e-business models. The focus is on the simple interactions between the firm and its customer and suppliers, which are drawn on a blank canvas. An indication of the direction of interactions is given, along with the type of flow. Thus, it adds value to an interaction in a way that is similar to e3-value; however, it is more general since it does not define ports or go into more detail about the flow itself.

## 2.2 2000-2004: Business Model Ontology

The development of BMO emerged from the need to define new business models for e-commerce around the year 2000. Following academic research, a first version of BMO was published in 2002 at the 15th Bled Electronic Commerce Conference by Osterwalder and Pigneur; it took the form of a framework that was specially targeted at e-businesses. Over the next two years, the work further matured, resulting in the publication of Alexander Osterwalder's thesis (Osterwalder, 2004) in which he described the key building blocks and their interactions. The model was presented as an ontology with elements of the modeled case becoming instances of the meta-level elements defined by the ontology.

Business Model Ontology in its original version uses nine building blocks to describe a business model: Value Proposition, Customer, Channel, Relationship, Revenue, Value Configuration, Capability, Partnership, and Cost. The model's scope is limited to the business itself and does not directly cover any environmental factors. Its key strength is the emphasis it gives to the relationship between the components. A coherent business model is created by correctly connecting elements from within the nine building blocks. Exploring these connections can help to identify missing elements or discover ambiguous assumptions within a model. In summary, BMO focuses on identifying **what** is provided to **whom**, **how** it is produced and **how much** profit it generates.

### 2.3 2004-2008: Use and Simplification

Following its academic publication (Osterwalder, Pigneur, Tucci, 2005) the model was used in two different contexts between 2004 and 2008. It was applied to tutorial cases delivered to IS students; thus, it was simplified, but still used in an academic context. The model was also used with practitioners in workshops and consulting sessions. Here, the model was applied to actual business problems in order to gain an understanding of how the model is used within a wide spectrum of business types, beyond just e-business models. Both of these applications sought to constraint the model as a one-page diagram. Special positioning was used to identify the type of each element and best practice was further strengthened by using keywords to describe each element. The changes were not only visual; the names of some of the elements themselves were also changed to better fit the vocabulary of its users. The nine names are: Value Proposition, Customer Segment, Distribution Channel, Customer Relationship, Revenue Stream, Key Resources, Key Activities, Partner Networks, and Cost Structure.

### 2.4 2008-2012: Business Model Canvas

Insight gathered during the previous years and the emergence of a small community around Alexander Osterwalder's blog led to the creation of a book project to communicate the result of these transformations. Convinced that the visual aspect of the model is a key component and largely influenced by the design-thinking movement and "managing as designing" (Boland & Collopy, 2004), the book was intended to offer a visual perspective. In turn, this led to a designer being brought on board to redevelop the layout of the canvas so that it became the Business Model Canvas (BMC) we know today. New features include the pictograms that illustrate the nine building blocks from the theory, their rectangular layout and an axis of symmetry around the value proposition (left side, right side). By providing examples from different industries, the book project further helped to crystalize the ideas on the usage of the BMC. In particular, it showed how the BMC can integrate a design-thinking process and explored the notion of partial meta business models known as patterns (Osterwalder & Pigneur, 2010).

To strengthen the link between theory and practice, the book was written in collaboration with the community. This was done by setting up a community hub with forums. Early drafts were published on the hub for review by subscribed members. This created a following of those interested in business model generation and further helped to promote the book. Many followers also put business model generation into practice, which eventually led to its success. From the start, the community was global in nature. Now, with many translations of the book made available, it is expanding even further.

Teaching of the BMC has been adopted by managerial and entrepreneurship courses in over 250 universities. In turn, this has increased adoption. Furthermore, there has been a steadily increasing number of workshops and consultant-led master classes, as well as internal education programs in large corporations.

Since the release of the book Business Model Generation in 2010, adoption of the BMC has grown to become a worldwide phenomenon: the original community hub of 400 people which helped create the book has grown to 14,000 members. The book itself has been translated into 29 languages and sold over 1,000,000 copies. Other communities, such as Customer Development (Blank & Dorf, 2012), have started using the BMC as a supporting model for their theories.

## 3 METHODOLOGY

In this study, we used Design Science Research (DSR), as described by (Gregor & Hevner, 2013). They defined a process in which artifacts are built and evaluated in an iterative process in order to solve the relevant problems. The need to take a visual approach to creating the BMC was driven by design-thinking theories and we identified need for practitioners to have better tools that can be easily integrated into daily practice. Existing knowledge of business model ontology has been described in the previous section. It was shown that Information Systems (IS) has the necessary body of knowledge to handle "strategizing as designing" (Osterwalder & Pigneur, 2013).

### 3.1 Users Maturity Level of Business Model Canvas Modeling

The BM canvas was evaluated using data and evidence from its use in the real world, books, canvas, hub, and the workshops and lectures that were used to inform the following three maturity levels inspired by the Common European Framework of Reference for Languages (CEFR), which also has three groups.

**Novice** – use the BMC as a simple common language and visualization help.

**Expert** – use the BMC as a holistic vision to understand and target a business model's sustainability. They understand the model's methods, such as high level links and colors, which helps to connect ideas and follow the interactions.

**Master** – use the BMC in the global Strategy, which is a process that evolves and adapts to its environment. They understand that the design of a model has to accompany such a process by supporting concepts of iteration, transformation (mutation) and choosing alternatives (selection).

*Having defined these three level of proficiency we use it to decompose the research question into three sub-questions:*

Novice level usage is the most commonly observed and fully applies to the static use of the BMC. Before moving to a dynamic representation of a business model, it should be guaranteed that at a static level it is already a coherent model. Which leads us to the following sub-question:

***How can the static design usage of the business model canvas be improved (in relation to its coherence)?***

Expert and Master level design of BMC are not observed frequently and lack representation due to their requiring a more dynamic aspect of the BMC.

For the expert with a focus on internal interactions this leads us to the following sub-question:

***How to represent the dynamic aspect of interactions happening inside the business model?***

Handling multiple states of a business model, due to internal or external changes, at the master level leads to the following sub-question:

***How to represent the transformation from one state to another of a business model?***

In the next section, we address these questions individually each with their own artifact.

## 4 ARTIFACT

In the next three subsection we consider each business model canvas design task of each mastery level by looking first at a metaphor of a similar design task in another design domain. Transposing the metaphor of house planning in architecture, plane building in engineering and evolution in biology to business model designing, we propose a concept to help answer each sub question. Each level builds on the previous and comes with their respective concept: BM Canvas Coherence, BM Mechanics and BM evolution, to address the dynamic nature of business models. We then illustrate how each concept applies to a small common example: the case of Apple's iPod business model. Each Artifact also describes in a short summary the essence of the mastery level to further offer a clear way to differentiate the three levels.

The following three concepts are presented below:

**BM Canvas Coherence** helps the novice to improve static business model modeling by way of using guidelines to check coherence of the business model.

**BM Mechanics** helps the expert by proposing to use colors and arrows to outline the interactions happening inside the business model.

**BM Evolution** helps the master by offering a way to visualize business model transformation from one state into another. Applying these transformation multiple times results in a branch showing the evolution of the business model.

A mapping between level and concept can be seen in table 1.

### 4.1 BM Canvas Coherence

At the novice level, the focus is on the concepts of the ontology, meaning the nine building blocks that define a business model. The main task consists of designing a business model by filling in elements for each block. Designing a business model can be best described using the metaphor of an architect engaged in designing a house. The architect needs to know about the various components of a house, such as the walls, doors, windows, roof and stairs, and also how they relate to each other. A wall can have windows and doors. A room has four walls with at least one door. Beyond such constraints, however, the architect is free to produce a variety of designs for a house. During the design process, the architect puts forwards his ideas using sketches and prototype models. These prototypes are not finished products, but are specifically aimed at testing the interaction of a selection of concepts in the specified context of the prototype. Transferring this design technique to a business model design means creating different business model variations of component interactions. For example, when prototyping a specific customer segment, the value proposition set could have its revenue stream type switched from paying to free, or from sales to subscription. This could then lead to further prototype changes to dependent components. This iterative validation of ideas leads to a business model that has all its components matching to become a “usable” business model. Checking the coherence between the elements is a key requirement for a valid business model. It is not enough to only produce a checklist of items without verifying their compatibility. Again, with reference to our architecture metaphor, stairs should be used to connect floors, and a door should lead to a room rather than nowhere. We call this “usability”. Similarly, in a business model, a value proposition needs to offer added value to a customer segment requiring it. A value proposition without a customer segment indicates a non-coherent business model. The iterative validation of design ideas can go as far as “getting out of the building” and test the assumptions directly with the potential customer as is done in Customer Development (Blank & Dorf, 2012). The gained insights may help to validate the hypothesis of the prototype or else offer new ideas to make a pivot of the model to target different customers.

In order to facilitate the checking of coherence, there are a series of guidelines which we have proposed to help validate the business model’s elements and interaction (Fritscher & Pigneur 2014c). They are split into three categories from element, to building block and interactions:

*Guidelines applying to individual elements* for example that the meaning of the element is understandable by all stakeholders.

*Guidelines applying to individual blocks* for example that the detail level of the elements are adequate (there are not too many detailed elements, nor too few which are too generic).

*Guidelines applying to connections between elements in different blocks* for example that there are no orphan elements: all elements are connected to another element (in a different block to themselves).

### 4.1.1 In Summary

At the novice level, the concepts of the model identify the right elements and how they are related to one another. An iterative process that explores detailed features of the elements helps to adjust the elements that make up the model in order to solve real problems. This leads to a coherent model that addresses the right job.

### 4.1.2 Apple iPod BM Canvas

In this example, we focus on Apple’s iPod business model. A model can be described by its elements, with keywords for each of the nine building blocks. Alternatively, illustrations can be used, as shown in Figure 1. The value proposition is a seamless experience that includes listening, managing and buying music. It is targeted at consumers who want to listen to music wherever they go and have access to a computer. The distribution channels to reach these consumers is a store or online-shop where the device can be bought along with iTunes software to manage the music library. Sales of the device generate revenue with higher margins than sales of the songs, where most of it goes to the majors. The customer relationship is oriented towards the lifestyle experience of Apple products. In order to offer these services, the key activity is the design of the device. Key resources are the device itself, music contracts, the developers and the Apple brand which strengthens the customer relationship. Marketing and developers are the key cost structures. Music licensing and device manufacturing is carried out through the partners.

This business model slice is coherent since as described each element is connected to another. There are no orphan elements, nor any combination of elements not connected to the rest of the business model.

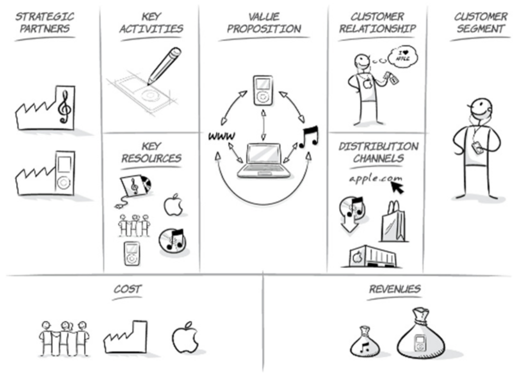


Figure 1: Apple iPod BM Canvas ©XPLANE 2008.

## 4.2 BM Mechanics

At the expert level, knowledge about the BMC and the requirement to design a coherent model is well incorporated into practice. The focus is on analyzing the interaction of the model’s elements beyond the relationships between them. It is not just about how one element relates with its connected elements, but about how they contribute to the overall thread of the business model story. A chain of interactions must be built from one element to another throughout their relationship. To continue with our comparison with other design domains, we move from architecture to engineering, where it is not enough to just know about the concept. An engineer needs to know about the underlying physics that supports the concepts. For example, it is not enough to know about the concepts that make a plane; we also need to know about their interactions. Without knowing how the aerodynamic properties of a wing generate lift, it would be impossible to design a plane that flies. Trial and error with prototypes that are not based on physical calculation would result in a large number of failures. What's more, the end result could not be explained fully. Similarly, in the design of business models, the activity has to move beyond prototyping and try to simulate the model to see if it is "workable". A good business model needs to both do the right job and be sustainable. Business model mechanics, outlines how elements influence each other beyond their relationship. The story can illustrate the flow of the exchange value between customers and the product and how it is produced. It is about understanding the underlying interactions which make the business model possible. In this context, explaining a revenue stream can for example depend on a partner (a relationship which is not defined in the basic ontology). These connections can be drawn using arrows at the top of the canvas to show the story. Elements can also be added to the canvas one after another while telling the story; this helps to strengthen the illustration. Another way to highlight the connectedness of elements is to use colors.

### 4.2.1 In Summary

At the expert level, the business model concepts of the canvas are well understood, and analysis has moved beyond the elements towards the interactions based on their relationships. The business model is coherent and does the right job. Above all, the interactions needed to make it work are understood. Thus, the model is the right one and has the potential to be sustainable if implemented correctly.

### 4.2.2 Apple iTunes BM Mechanics

In the case of the Apple iTunes, two stories can be identified (see Figure 2): the music part (shown using dotted lines), and the device (iPod) and brand part (shown using dashed lines).

In order to make the platform attractive, Apple had to offer a broad selection of titles, including all the popular songs. This was achieved by making deals with all the big majors. Skill and leverage were required to be able to make deals which will make the platform competitive on pricing and title selection. Initially, to get the majors on board Apple added Digital Rights Management (DRM) to protect the digital music files; this had the side benefit of locking the user in to Apple's devices and software platform.

On the device side, functionality and esthetics had to be combined in the design activity to create a product which is in line with the customers' brand expectations.

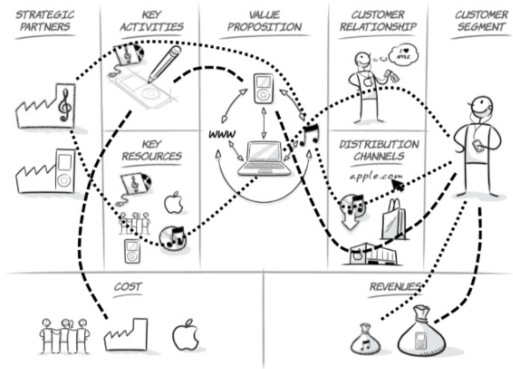


Figure 2: Apple iPad BM Mechanics adapted from ©XPLANE 2008.

## 4.3 BM Evolution

At the master's level, any considerations go beyond the current business model. Masters are not afraid of the unknown and are ready for anything. There is an understanding that the strategy has to have a longer-term vision that extends beyond the current business model, and that to survive, it has to be able to evolve. The focus is on actions that can be taken to evolve from one business model to another. In order to be aware of incoming changes, observation of the business model's environment is key. Our architecture and engineering metaphor has its limits; indeed, we would need to use analogies from the realm of science fiction to illustrate transforming behaviors. Therefore, a better analogy is the concept of biological evolution. Individual business models can become obsolete and die off; however, the "species" evolves and survives through mutation and selection. This means that in order to survive decay, new business models (mutations from existing ones) have to be tested continuously. When proven successful, they are selected. Sometimes, the previous business model might even be cannibalized by it.

A business model can do the right job and be sustainable and still fail if it is not adapted to its environment. Unlike our biology analogy, the variations of a business model can be planned so that it can be ready to adapt when the environment changes. This involves planning different business models for a range of scenarios (Schoemaker, 1995) and then being ready to switch to them depending on the environment. The adaptability of a business model to its context is key.

Various external occurrences may affect the business model at any time; thus, different alternatives need to be kept should one of them become a reality. Keeping track of the mutation in relation to external stimuli necessitates the management of different versions of the business model. The creation of multiple versions of a business model to address different external environments is a first step. Another step is to know how to adapt from one version of a model to another. In this case, the transformation between them needs to be highlighted. For that purpose, we propose to use the concept of transparent layers to stack business models parts on top of each other. On paper this can be done with tracing paper, each new layer can show new elements and reuse of element which are visible in a semi-translucent fashion from lower layers.

Together, the two steps allow us to evaluate a model in the light of external factors, thus enabling us to select the business model that fits best.

The combination of multiple transformation from a given state help form a graph or a tree with branches of possible evolution paths to follow for the future business model. As well as to visualize the past transformations which lead to the current state of the business model.

### 4.3.1 In Summary

At the master's level, business model concepts and interactions (story) are well understood, both in terms of a single model and the analysis of multiple models. Decisions are made with the environment in mind in order to deploy the right model in the right context. Using this strategy, business models can be evolved to adapt to any change.

### 4.3.2 BM Evolution: From Apple iTunes to Apple App Store Business Model

The transformation from a music service to a software platform has many innovation drivers. A major one which can be highlighted in Apple's case was their capability to create a touch-based screen for a phone device by combining new external technology (touch hardware) with internal knowledge of the design of human friendly interfaces (custom software).

To create the App Store business model (seen in Figure 3), Apple evolved their iTunes business model by reusing existing components, expanding others and adding new ones. Apple capitalized on its knowledge of design, value chain management and store to build and distribute a new touch based phone (iPhone). New components included the extension of the distribution channel to also include the new partner, the mobile phone operators. Taking advantage of their knowledge of building software development kits for computers, Apple created a development kit for the phone which is targeted at a new customer segment of developers to create mobile apps. To manage the quality of these apps and handle financial transactions, a validation process and revenue sharing model had to be put in place. Putting these pieces into place helped to create an eco-system that connects phone users in need of specialized apps with a large developer community willing to provide them for a small price. This transformation was much more than a product innovation; rather, the whole business model moved to a double sided business model (Eisenmann, Parker, & Alstyne, 2006), connecting the developers with the phone users.

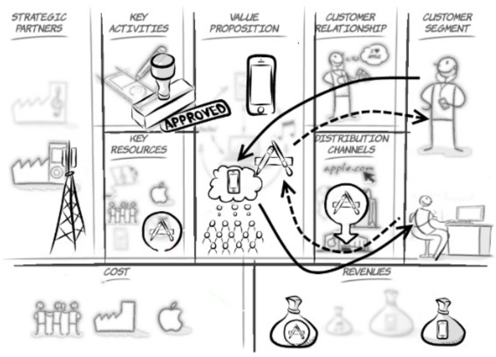


Figure 3: Apple iTunes to App Store adapted from ©XPLANE 2008.

## 5 EVALUATION

The first evaluation of the proposed concept is their instantiation into cases. Being able to use the concept to represent real world business models demonstrates the validity of the artifact. The second part is to show their utility having user employing the proposed technics to represent their own business models. Since the proposed concept are still very early ideas, a further step would be to refine them. This would allow for them, for example, to be implemented into a computer-aided design tools for business models. Providing advantages of automating some of the concepts' more tedious interactions such as validating constraints, editing arrows paths and changing visibility of elements.

For each of the BM concepts explained in the previous section we present the goal solved by an artefact we built to demonstrate its instantiation. We give a summary of our related work findings and propose some further possible evaluations.

## 5.1 BM Canvas Coherence

*Goal: evaluate how rules can help beginner build more coherent business models.*

Useful validation questions and best practices emerged during the years of teaching workshops on the business model canvas. Some of which have been formalized into guidelines and applied to build an expository case business model (Fritscher and Pigneur, 2014c). This could then be evaluated to see how automated validation of the coherence of a business model can assist the creation of better business models. In the process of testing user experience and idea generation differences between paper and digital business model design, we also did initial testing on coherence guidelines on paper with a group of students. This showed that they lacked the perseverance to rigorously apply them manually and highlights the need to perform experiments with computer aided systems.

## 5.2 BM Mechanics

*Goal: evaluate how visual help such as color tagging can help provide a clearer picture.*

Drawing arrows on top of business models is also something that emerges naturally in design session. Therefore it is already somewhat in use although not in a guided fashion. However, it is not always used as described in the bm mechanics technique. Previous work has shown that formalized links do not get adopted by the users, instead color tagging of elements can be used (Fritscher and Pigneur, 2014b). We tested how tagging elements with different color can help get a better visual picture without increasing the visual legibility. This suggests that for formalizing the BM mechanics feature, attention should be focused on not making the arrow interaction too constraining or complicated.

## 5.3 BM Evolution

*Goal: Evaluate the usefulness of the layer concept to represent business model transformations.*

The business model evolution concept with its two parts: transformation (mutation) and path of possible (selection) is a somewhat complicated concept. Especially to create the visual representation on paper. Wanting to explore alternatives can lead to a lot of copy work and stacking multiple versions of transformation on top of each other can get visually cluttered. An initial instantiation into a Computer Aided Design (CAD) tool has been attempted and shows promising results (Fritscher and Pigneur, 2014d). The creation of the prototype tool lead also to the building of a case which describes a real world business model evolution over seven transformations and two business models evolving in parallel[1]. This illustrate the potential of using a layered visual approach to represent the dynamic nature of business model evolution.

# 6 DISCUSSION

Although we presented the three concept separately, each successive level of maturity builds on top of the previous ones. A business model has to be coherent in itself before exploring its dynamic aspect. The prototype built to support BM evolution visualization also supports drawing of arrows for BM mechanics. This shows that the feature of drawing arrows combines itself nicely with the layers that support the transformations of the evolution. This combination which provides means to decompose the internal story into states that from a temporal segmentation of the actions happening in the business model story. This can then be visualized with layers as the evolution of the story.

Implementing prototypes to support the concept required to identify how the different design technique can be support by CAD functions. We summarize them in the next section.

Documenting the transformation which BMO went through to get adopted by practitioners gave us some insight into elements which made it possible. We present our observation in the section entitled: Lessons learned for business model methods designers.

## 6.1 Design Techniques and Supporting Cad Functions

In table 1 we provide a summary of the key design techniques and supporting CAD functions for each concept of the three maturity levels.

At the novice level, BM Canvas Coherence can be improved by following guidelines. It is possible to formalize these guidelines into verifiable rules. This in turn allows to perform validation or trigger contextual hinting assistance with a CAD tool. In order for the tool to get a better model, it is needed to indicate some of the elements relationship. This can be accomplished by tagging them into different colors, which is simpler for the user than explicitly connecting them with links.

[1] Valve Corporation – Business Model Evolution Case http://www.fritscher.ch/phd/valve/

At the expert level, BM mechanics helps to provide a clearer picture on the internal interaction of the business model. In order to support such storytelling, functions like color and arrows can be used on top of the BMC. In addition, a CAD tool can help by toggling the visibility of elements as the story progresses allowing for a dynamic representation of another ways static canvas. This temporal execution of the models' story can then be tailored to the individual stakeholders, the dynamic management of the visibility allowing to support multiple stories on the same canvas.

At the master level, BM Evolution helps to address the transformation required by renovation and exploration of possible future states envisioned by scenario planning. Through layers, versioning and by allowing to compute custom views of superposing layers CAD tools offer dynamic visualization showing any chosen past, present or future state of a business model. Also by chaining the transformations, it can be known which change affects any descendant element's future state. A new computation of these updated views can be performed by the tool without any work from the designer.

### 6.2 Lessons Learned for Business Model Methods Designers

Based on the lessons gained from our experience we can share the following observations on the possible influences on the success of a business modeling methods. These will help to broaden the adoption of an academic enterprise ontology by practitioners:

Designing a method that can scale in complexity for various proficiency levels, from novice to masters, helps its adoption.

Performing design science evaluation cycles and evolving the method after each evaluation is key to identifying the right balance between simplification and the re-addition of elements at different proficiency levels.

Finding the right community is important: people need to be willing to quickly test and iterate the model's concepts. (In our case, entrepreneurs were the ideal test participants; it is in their nature to try out business model concepts, which allowed for quick iterations).

Providing a tool (free canvas and book) empowers teaching at a university level as well as in workshops, thus helping to spread the method.

## 7 CONCLUSION

Starting from observation on the evolution and adoption of the BMC we identified the need to address the issue of **how to represent and help to design the dynamic aspect of a business model with the Business Model Canvas**. Based on observations we *identified three maturity levels* of business model canvas design and addressed the issue by splitting the question into three sub-questions:

**How can the static design usage of the business model canvas be improved (in relation to its coherence)?**

At the novice level, the simple nature of the canvas helped in its adoption. This simplicity lends to the use of building blocks as a checklist. It is however necessary to keep in mind the relationship between the elements in order to maintain the underlying ontological nature of the business model theory. *Guidelines can help to verify these relationships and thereby help to create more coherent models.*

**How to represent the dynamic aspect of interactions happening inside the business model?**

At the expert level, it is necessary to understand the big picture. Showing a completed model to a person for the first time would overload them with information. Thus, design-thinking mechanics, such as storytelling, have to be used to present the BM mechanics of a model one step at a time. This allows users to understand all the elements of a business model, as well as the way they interact with each other. *These interactions can be further strengthened by drawing arrows to outline the main story thread in what we call BM Mechanics.*

**How to represent the transformation from one state to another of a business model?**

At the master level, it was found that making different versions of a business model could help in analyzing its reaction to the context. The management of these versions quickly became a constraining factor, particularly if only part of the business model changed. *Using layers to illustrate only the changes is a design technique that helps to overcome some of these constraints. Having the means to describe transformation from one state into another, can then be combined to form a chain of transformation leading to a tree of possible path of evolution for the business model in what we call the BM Evolution.*

Table 1: Summary of concept, design technique and CAD functions.

| Maturity | Concept | Design Technique | CAD functions |
|---|---|---|---|
| Novice | BM Canvas Coherence | Guidelines, rules | Colors, validation, |
| Expert | BM Mechanics | Storytelling | Colors, arrows, |
| Master | BM Evolution | Renovation, what-if, scenario planning | Layers, versioning, |

To conclude, we provide several opportunities that could be further investigated for each of the discussed levels.

## 7.1 Opportunities

The business model ontology can be directly extended in several ways. However, it is most advantageous to capitalize on the diffusion and knowledge of the current version. We argue that it is helpful to develop extension as a plugin. For example, a customer segment can be analyzed through the lens of such tools as personas and customer insight or through the framework of jobs to be done (Johnson, 2010). The current focus on plugins is mainly on the value proposition and the customers, or the connection between the two. There are many more elements, however, that could benefit from in-depth analysis at a component or relationship level. Those that come to mind include categorizing the channel based on the time and type of interaction of the client-to-customer relationship for this particular event; this would make better use of the customer relationship component. Key activities can be decomposed into types and supporting applications. This allows us to better align the enterprise architecture, its business processes and infrastructure to the business model (Fritscher & Pigneur, 2015).

Beyond small transformation of business model, research into a theory of evolution for business models is of great interest, particularly in identifying why some business models survive change better than others.

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# Tailoring the Business Modelling Method for R&D

L. O. Meertens, N. Sweet and M. E. Iacob
*University of Twente, PO Box 217, Enschede, The Netherlands*
*{l.o.meertens, m.e.iacob}@utwente.nl*

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Abstract: While the benefits of innovation seem to be clear intuitively, Research and Development (R&D) organisations are struggling to show the value they add. Especially in times of crisis, the result is that they get the first budget cuts to reduce costs in the short term. This causes companies, industries, or even whole economies, to lose competitive advantage in the long run. The field of business modelling deals with the creation and capturing of value. However, it has not yet provided a method tailored to R&D previously. Building upon earlier work on business modelling, we adapt the Business Modelling Method (BMM) to the field of R&D.

## 1 INTRODUCTION: CREATING VALUE WITH R&D

For a company to grow, it must keep ahead of competitors whenever possible. To do this, companies must innovate, which often depends on Research and Development (R&D). Following this reasoning, investing in R&D would give competitive advantage. However, it is not that simple. A higher R&D spending does not automatically lead to more or better innovation. R&D is difficult to manage, while the success is not known in advance.

Because the direct effect is hard to measure, it is interesting to see how R&D adds value. This question remains unanswered since the beginning of research on R&D.

The field of business modelling researches the creation and capturing of value. A business model is a simplified representation of reality which tries to show how a company does business or creates value.

It is interesting to combine the fields of R&D and business modelling to expose the business model behind R&D. Translation of this interest to scientific research leads to the main research question of this paper:

> How to build a business model for a research and development organisation?

The research question combines two scientific areas, the one of business model research and the one of R&D research. R&D research is related closely to innovation research and is intertwined with various fields of expertise, such as knowledge management, marketing, production, and so on.

Business modelling is a field with many changing factors in the past two decades. The rise of information technology, the introduction of a new distribution channel ‘the internet’, and other new forms of communication, together with the rise of globalization, makes business model research an interesting topic (Osterwalder, Pigneur, & Tucci, 2005).

Based on Vermolen (2010), Meertens, Iacob, & Nieuwenhuis (2011) conclude that current literature provides no methodological approach for the design and specification of business models. In an attempt to make business modelling a science instead of an art, Meertens et al. (2011) propose a method that enables the development of business models in a structured and repeatable manner. They jump in one of the research gaps defined by Vermolen (2010), as ‘Design’, and by Pateli and Giaglis (2004), as ‘Design tools’. In this paper, we further advance this method by demonstrating how it can be tailored. In this case, we tailor it for the field of R&D.

The structure of the paper is as follows. Section 2 reviews current literature on business modelling and identifies typical characteristics of research and development. Section 3 provides a design science method to tailor the BMM to R&D. By applying that method, section 4 tailors BMM based on R&D characteristics. In section 5, the first four steps of the tailored BMM are demonstrated by means of a case study. The last section consists of conclusions and provides directions for further research.

# 2 LITERATURE REVIEW: BUSINESS MODELLING AND R&D CHARACTERISTICS

This section is divided in two parts: business modelling and R&D characteristics. First, in the business model section (2.1), a business modelling method is chosen and presented. Then, in the R&D section (2.2), the characteristics of R&D are discussed.

## 2.1 Business Modelling

The term ‘business model’ is often used, especially in the entrepreneurial and management field, but also in other areas. The combination of these two words is used for multiple purposes with significant different meanings. This is mostly due to the fact that the term comes from different perspectives like e-business, strategy, technology, and information systems (Zott & Amit, 2010). In 2005, (Shafer, Smith, & Linder, 2005) found 12 definitions in literature with 42 different components. At the same time Osterwalder et al. (2005) received 54 different definitions from participants in the IS community. Nevertheless, no consensus concerning the definition of a business model (Pateli & Giaglis, 2004; Vermolen, 2010) from an academic perspective has been reached. In this research, the definition given by Meertens et al. (2011) is followed: “*A business model is a simplified representation that accounts for the known and inferred properties of the business or industry as a whole, which may be used to study its characteristics further...*”.

We choose this definition, as it indicates the use of a business model, not only as a design artefact, but also from a business engineering perspective.

Besides the lack of a generally accepted definition, no widely accepted methods for the design of business models exists. To the best of our knowledge, Meertens et al. (2011) propose the only method to build a business model in a generic and systematic way. Therefore, we focus on this Business Modelling Method (BMM) in this paper. Application of this method results in at least two business models. One business model reflects the ‘as-is’ (current) situation of the business, and the other reflects the ‘to-be’ (target) business model(s). This represents the potential impact on the business model after adoption of innovative technologies or more efficient business processes (Meertens et al., 2011).

The BMM describes six steps using specific methods, techniques or tools. The first four steps concern the creation of the ‘as-is’ business model:

1. Identify roles
2. Recognize relations
3. Specify activities
4. Quantify model

The remaining two steps concern developing the ‘to-be’ model:

5. Design alternatives
6. Analyse alternatives

Meertens et al. (2011) provide the BMM only as a baseline methodology, with a limited amount of concepts. The methodology has to be extended and/or tailored to specific situations. Each of the steps can de detailed further by inserting applicable techniques. The specific situation for this research is an R&D organisation, which means that the known and inferred properties of R&D are needed to tailor the method.

Table 1: Concept matrix of selected R&D literature.

| | Project management | Managing activities | Risk management | Cost management | Value | External linkages |
|---|---|---|---|---|---|---|
| **(Ali, 1994)** | | | ● | | ● | |
| **(Balachandra & Friar, 1997)** | ● | | ● | | | |
| **(Brockhoff, Koch, & Pearson, 1997)** | ● | ● | ● | | | |
| **(Chesbrough, 2003)** | | | | | | ● |
| **(Coombs, McMeekin, & Pybus, 1998)** | ● | | | | | |
| **(Sherman & Olsen, 1996)** | | | ● | | | |
| **(Healy, Myers, & Howe, 2002)** | | | | ● | | |
| **(Kleinschmidt & Cooper, 1991)** | | | | | ● | |
| **(Lev, Sarath, & Sougiannis, 2005)** | | | | ● | | |
| **(Liberatore & Titus, 1983)** | ● | | | ● | | |
| **(Morandi, 2011)** | | ● | | | | ● |
| **(Nobelius, 2004)** | | | | | | ● |
| **(Pinto & Covin, 1989)** | | ● | ● | | | |

## 2.2 R&D Characteristics

To discover the known and inferred properties of R&D, we review the literature to investigate what the specific characteristics of R&D are. We follow an explicit and systematic methodology to conduct the literature review. Based on the literature review, we selected the relevant and useful papers for this research (Sweet, 2012).

By analysing the selected literature, we derive the main concepts used to describe R&D. Table 1 shows a concept matrix with the selected literature. Each of the concepts is characteristic of R&D. In the following sub-sections, we discuss each of the characteristics.

### 2.2.1 Project-oriented

Liberatore and Titus (1983) notice that R&D management research has an emphasis on project management, which is in line with the conclusions of Coombs, McMeekin, & Pybus (1998), and others (Balachandra & Friar, 1997; Brockhoff, Koch, & Pearson, 1997), that project management has an important role in R&D.

R&D consists of projects. Pinto and Covin (1989) state that projects usually have the following attributes:

1. a specified limited budget
2. a specified time frame or duration
3. a preordained performance goal or set of goals
4. a series of complex, interrelated activities

These attributes lead to a set of characteristics and issues, which are specific for R&D.

### 2.2.2 Risk Management

Pinto and Covin (1989) notice the overt risks, which are familiar to R&D projects. Ali (1994) mentions a lack or loss of project support and uncertain resource requirements. The duration of an R&D project can be very long (Brockhoff et al., 1997), especially for radical innovation (McDermott & O'Connor, 2002; Veryzer, 1998), which makes it harder and more risky to determine the allocation of resources and set reasonable goals. The same goes for project support, which is important for R&D, because R&D benefits are often only seen on the long term and success rates are often low (Pinto & Covin, 1989; Sherman & Olsen, 1996). The outcomes of R&D projects are difficult to predict (Balachandra & Friar, 1997; Brockhoff et al., 1997; Pinto & Covin, 1989), which, together with the managerial aversion of taking risk, makes risk management an important R&D characteristic.

### 2.2.3 Managing Activities

R&D activities are often considered as a black box, which is hard to systematically manage and control. According to Brockhoff et al. (1997), R&D activities are more often non-repetitive. Which is in line with Pinto and Covin (1989), who state that activities involved in R&D project execution are less amenable to scheduling. A project is a series of complex interrelated activities and the task uncertainty (Morandi, 2013) involving R&D processes makes it even more complex. However, because it is difficult to manage and control R&D activities, this does not mean it should be neglected. It is a common understanding that the distinguished types of innovation need to be managed differently. Incremental innovation is more structured than radical innovation, therefore the same management and control techniques cannot always be used interchangeable.

### 2.2.4 Value

Value is hard to determine because the success of the outcome is not known. Even if the outcome definitely leads to a patent, then the lifetime of that outcome or product is not predictable. The expected returns from incremental innovations are lower than from radical innovations (Kleinschmidt & Cooper, 1991). However, the risk associated with their development and commercialisation is lower than from radical innovations. Incremental innovations are important for the firm's overall profitability (Kleinschmidt & Cooper, 1991).

### 2.2.5 Cost Management

Liberatore and Titus (1983) address the existence of cost-effective techniques that can improve project management for R&D. However, costing techniques may not directly apply because of (lack of) availability of information, which is in line with earlier mentioned uncertainties. Uncertainty is why financial accounting rules treat R&D as an expense instead of the capitalisation of costs (Healy, Myers, & Howe, 2002; Lev, Sarath, & Sougiannis, 2005). Because the success of a R&D project is not known, and neither is the eventual life time of the R&D outcome, it is impossible to capitalise the R&D costs without the big risk of manipulation of earnings (Healy et al., 2002; Lev et al., 2005). The downside is that intangible assets are often undervalued.

### 2.2.6 External Linkages

Rothwell (1994) mentions five generations of R&D. Characteristic for the fifth generation is the emphasis on external linkages, in other words R&D as a network. The focus is on collaboration within a wider system, involving competitors, suppliers, distributors, etc.(Nobelius, 2004). This is in line with open innovation that Chesborugh (2003) proposes. He defines it as a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as firms look to advance their technology.

# 3 METHOD: DESIGN SCIENCE APPROACH TO TAILOR THE BMM TO R&D

Tailoring the BMM to R&D is a typical example of design science. The result of this research consists of artefacts at two levels according to the levels of Gregor and Hevner (2013). We aim to contribute with a second level (adapted method: the BMM4R&D) and a first level (applied case: SBT) artefacts. We do not have the intention to contribute to the third level (grand design theory).

In the light of Gregor and Hevner (2013), we position our research in the exaptation quadrant. Exaptation in this context means that we attempt to use the previously developed Business Modelling Method (BMM) in another field: the field of Research and Development (R&D). To achieve this, we tailor the BMM for R&D by placing the right methods in the slots/steps of the BMM, according to matching with R&D characteristics.

In this paper, we attempt "to demonstrate that the extension of known design knowledge into a new field is nontrivial and interesting. The new field must present some particular challenges that were not present in the field in which the techniques have already been applied" (Gregor & Hevner, 2013, p. 347).

The BMM contains prescriptive knowledge at the second level (Nascent design theory—knowledge as operational principles/architecture (Gregor & Hevner, 2013, table 1)). Originally, it was developed as a typical example of the improvement quadrant, where a new solution was developed for a known problem.

To adapt the existing BMM, we build on methodology engineering as coined by Kumar and Welke (1992) and further developed by Brinkkemper (1996). More recently, Henderson-Sellers and Ralyté (2010) captured the state-of-the-art on (situational) methodology engineering. The methodology engineering viewpoint has two aspects: representational and procedural (Kumar & Welke, 1992). The representational aspect explains what artefacts are looked at. The artefacts are the input and deliverables of phases in the method. The procedural aspect shows how these are created and used. This includes the activities in each phase, tools or techniques, and the sequence of phases.

In this research, we focus on the procedural aspects, as the input and deliverables of each step are quite well defined and suitable for almost any specific situation where a business model has to be created. Therefore, for each step (phase) in the BMM, we reconsider the tools and techniques proposed in the original method. For each step, we investigate the literature for existing methods (tools/techniques) possible in that step. Then, we compare those to the R&D characteristics from the literature review in the previous section. Based on this comparison, and consideration of the originally proposed method, we choose a method that best fits the particular challenges of R&D. Thus, tailoring the BMM for R&D. To demonstrate that the tailored method works, we apply in two cases in an R&D organisation.

# 4 TAILORING THE BUSINESS MODELLING METHOD FOR R&D

In this section, the first four steps of the BMM are assessed against the R&D characteristics from section 2.2. Step 5 and 6 are based on the first four steps or use general techniques such as brainstorming. It is not needed to assess them against the R&D characteristics. Meertens et al. (2011) proposed specific methods, techniques or tools that are suitable, but they remark that other techniques may be useful and applicable as well. Therefore, based on literature reviews for every step, a possible set of suitable techniques for BMM in an R&D setting is presented.

Before the tailored BMM is presented, it is important to understand that this method is based on the assumption that a R&D organisation is considered as a portfolio of projects. This assumption is in line with literature (Balachandra & Friar, 1997; Brockhoff et al., 1997; Coombs et al., 1998; Liberatore & Titus, 1983; Pinto & Covin, 1989), but from the logic that the projects create the value as well.

## 4.1 Step 1: Identify Roles

One of the difficulties in '*Risk management*' is the often long time frame of R&D projects. While time passes by, the interests of stakeholders change. The stakeholder analysis (Elias, Cavana, & Jackson, 2002) focuses on the dynamics of stakeholders and their changing interests. In this way, possible risks can be foreseen and acted on.

Another focus of this stakeholder analysis is the characteristic '*External linkages*', which is implicitly a part of every stakeholder analysis. This stakeholder analysis distinguishes itself by conducting an analysis on three levels, rational, process, and transactional. This way, it gives a deeper insight in the management of relations as well as the transactions that take place. This information supports management of risks.

## 4.2 Step 2: Recognise Relations

The second step of the BMM aims to discover relations among the roles. It may appear that relations are already captured in the stakeholder analysis of the first step and therefore this step is redundant. However, several reasons exist why the recognition of relations is a separate step in the BMM. First of all, a stakeholder analysis often follows a hub-and-spoke pattern, as the focus is on one of the roles (Meertens et al., 2011). Meertens et al. (2011) suggest a role-relation matrix as a deliverable, as this approach forces to specify and rethink all possible relations between the roles. Secondly, they note that relations always involve some interaction between two roles. Furthermore, they assume that this interaction involves some kind of value exchange as well. This is in line with Gordijn and Akkermans (2001) who state that all roles in a business model can capture value from the business model. From this perspective, the proposed technique for this step, e3-value modelling, is a valid one. The e3-value model models the economic-value exchanges between actors (Andersson, Johannesson, & Bergholtz, 2009; Kartseva, Gordijn, & Tan, 2006). This economic-value exchange can be tangible as well as intangible (Allee, 2008; Andersson et al., 2009). The initiators, Gordijn and Akkermans (2003), present the e3-value model as being:

1. lightweight
2. a graphical, conceptual modelling approach
3. based on multiple viewpoints
4. exploits scenarios, both operational and evolutionary
5. recognising the importance of economic value creation and distribution

Properties 3 and 5 are in line with the choice of this model in this step. The multiple viewpoint approach is the missing link between the stakeholder analysis and the role-relation matrix. Furthermore, the focus on value exchange fits the property of a relation being an interaction between roles with some kind of value exchange. The remaining properties 1, 2, and 4 are useful in step 5 of the BMM. The lightweight and visual-oriented approach facilitates brainstorming and generating scenarios, which are important aspects of step 5.

Two R&D characteristics, which are relevant for this step, are '*Value*' and '*External linkages*'. The value exchange of intangible assets is an exchange that occurs often, as knowledge transfer goes hand in hand with R&D. By exposing the tangible value exchanges, as well as the intangible ones, the e3-value model is suitable for R&D from a '*Value*' perspective. This automatically shows that this model is suitable from the perspective of '*External linkages*' as well. External linkages are the relations between different roles, for example a supplier, and the exchange of for example knowledge. The strength of the e3-value model lies in business network environments and an organisation together with their external linkages can be typed as a business network.

## 4.3 Step 3: Specify Activities

Meertens et al. (2011) propose techniques from business process management to create the intended output. However, in contrast to the example, R&D activities are considered as a black box, which makes them hard to specify. It is possible to cluster activities in groups, but the number of techniques offered by business process management is considerable, it is necessary to look deeper into the field of business processes in R&D.

## 4.4 Step 4: Quantify Model

For an organisation to assign costs, several systems are available, which can be distinguished in traditional systems and more refined systems, such as Activity-Based Costing (ABC) (Drury, 2008). Process costing, job costing, and a hybrid form of these two are considered as traditional systems. Process costing allocates costs to masses of identical or similar units of a product or service, and job costing allocates costs to an individual unit, batch, or lot of a distinct product or service (Horngren et al., 2010). Not only products or services can be cost objects, also a customer, product category, period, project (R&D / reorganisation), activity or a department may qualify as a cost object. ABC refines a costing system by assigning cost to individual activities.

ABC is not a suitable technique for R&D as activities are clustered and complex. Process costing is used to cost masses of identical or similar units. One of the characteristics of R&D is its non-repetitive nature (Brockhoff et al., 1997), therefore process costing is not suitable for R&D. Job costing, on the other hand, allocates cost to an individual unit, batch, or lot of a distinct product or service. As mentioned, this research considers an R&D organisation as an organisation that is built on projects. Although project management techniques are used to create uniform structures, such as New Product Development (NPD) processes, this does not mean that process costing can be used. These kinds of structures do not cluster uniform activities but try to support the process of delivering certain outputs. Each output is unique or has its unique features and therefore job costing is a suitable technique for R&D.

# 5 DEMONSTRATING THE BUSINESS MODELLING METHOD: THE SE BLADES TECHNOLOGY CASE

Suzlon Energy Blades Technology (SBT) is an R&D division of Suzlon Energy Limited and is specialised in the design and development of rotor blades for wind turbines. The division is spread out over four locations: Hengelo (Netherlands), Århus (Denmark), Pune, and Baroda (India). SBT is a project-oriented organisation as most R&D organisations. Earlier, it is stated that an R&D business model is a portfolio of innovation processes. At SBT these innovation processes are reflected in new product development (NPD), design change management, and technology projects. The NPD projects 'directly' create value for the organisation, where the technology projects are feeders for NPD projects. Finally, the design change management projects are the continued development of NPD projects. The innovation process for NPD projects is already imbedded in the organisation in the form of a Stage Gate System (see section 5.3).

In this case study, we examine two NPD projects after the implementation of the stage gate system. Both projects together should give a good perspective on the innovation process of NPD's at SBT and gives us the opportunity to demonstrate the BMM4R&D.

## 5.1 Identify Roles

Suzlon is a multinational company with complex relations. First of all, the business unit SBT itself is internationally situated. It has to deal with various cultures and different interests within the R&D departments, and with the manufacturing in India as well.

Furthermore, the interests of the wind turbine division, overall Suzlon interests, and of course market needs and market opportunities always play a role. This reflects on current NPDs, future NPDs, current and future technology projects. In this study, the NPD is the unit of analysis, because an NPD can be seen as an example of the generic NPD process within SBT. The project teams consist of the recurring roles. Although the location of these roles may differ per project, the built up of a project team is generic. Furthermore, internal stakeholders are not taken into account, because research on roles within projects is largely available.

For the sake of clarity, stakeholders in this paper are combined and renamed. The stakeholders are addressed per stage of the NPD (see section 5.3).

Suzlon Energy GmbH (SEG) and SBT manage their organisations independently, which influences an NPD on different levels. Not only do they interact with each other, external factors as political change or economic crises can have direct influence on each project. The portfolio boards translate market needs and opportunities into product strategies. NPD and technology projects are derived from this strategy.

Table 2: Stakeholders per stage.

| Stakeholder | 1 | 2 | 3 | 4 | 5 | 6A | 6B |
|---|---|---|---|---|---|---|---|
| **SEG (Suzlon Energy GmbH)** | ● | ● | | ● | ● | ● | ● |
| **SBT (Suzlon Blade Technology)** | ● | ● | ● | ● | ● | ● | ● |
| **PB SEG (Portfolio Board SEG)** | ● | ● | ● | ● | ● | ● | ● |
| **PB SBT (Portfolio Board SBT)** | | ● | ● | | | | |
| **NPD SEG (NPD on overall level)** | | | | ● | ● | ● | ● |

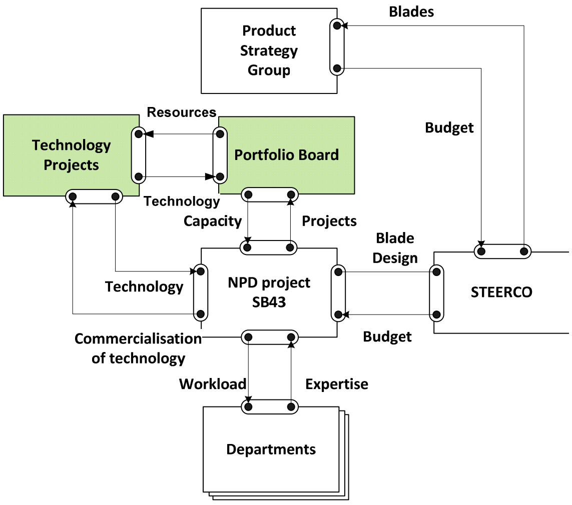


Figure 1: e3-value model of SB43 Stage 3.

Most of the time the influence of the portfolio board is long term, but some market changes need to be reacted on quickly. Therefore, the potential influence of such a stakeholder is always present. Finally, the NPD SEG contains representatives from the whole chain (R&D, moulding, purchasing, manufacturing, services, finance, etc.). Every decision can influence the financial cost of the other. Especially here, the tension of the various forces can be intense.

These stakeholders are returning stakeholders during every project and therefore people know by experience how to act. The play of forces of the different stakeholders' interests, culture and politics are managed by imbedded procedures and RASCIs. The influence of the stakeholders at each stage differs (see Table 2). Furthermore, an unexpected event can lead to big power impact of a stakeholder which would not have much influence during a certain stage under other circumstances. Therefore, it is important to give more insight in the relations between these stakeholders in the next paragraph.

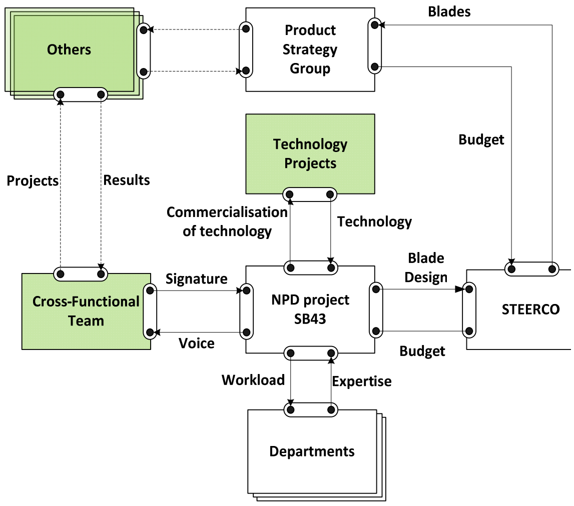


Figure 3: e3-value model of SB43 Stage 4, 5, 6.

## 5.2 Recognize Relations

In the first step, we mapped the stakeholders per stage and we do the same for this step, using the e3-value model per stage. When done for every stage, we get an extended view on the influence of stakeholders: not only on the power aspect but on the value aspect as well. Figure 1 shows the e3-value model of stage 3.

During the case study, an economic crisis influenced the market dramatically. Governments economised on subsidies for alternative resources such as wind energy, which directly influenced budgets. Other possible scenarios, such as radical innovation because of a breakthrough in a technology project, capacity problems in a department, or a political change can be assessed per stage using the e3-value model.

## 5.3 Specify Activities

An organisation needs to adapt the Stage-Gate system according to its own needs (Cooper, 2009). This

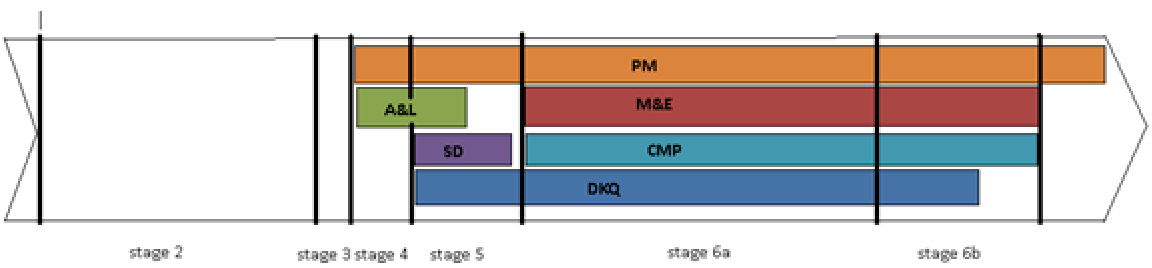


Figure 2: Departmental activity per stage.

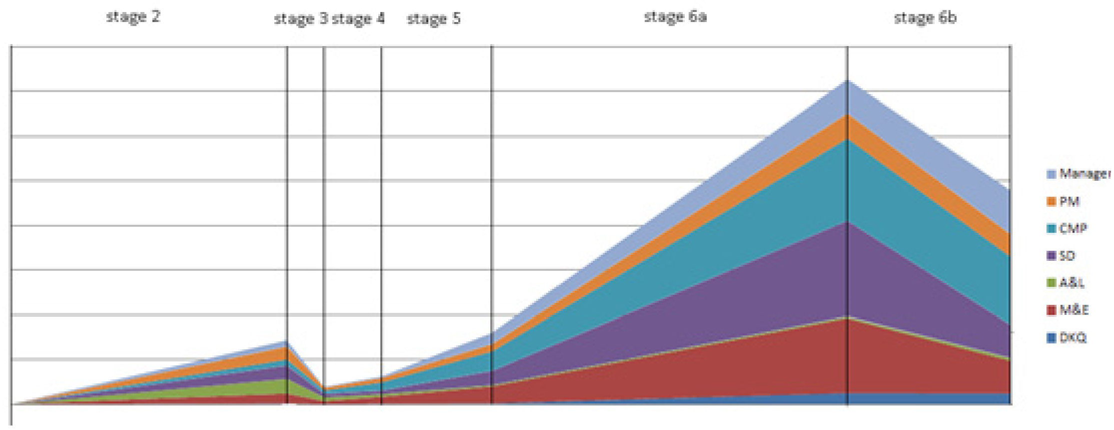


Figure 4: Hours of departments involved at each stage.

allows the method to be applicable to various kinds of R&D organisation. At SBT, all the stages are present, but stages are split up, and/or named differently, to fit with the specific situation of SBT. Although stage 1 is part of the NPD process, it is not part of an NPD project. In the best case, the activities of stage 1 are assigned to a Technology project and, if possible, an NPD project is set up at the start of stage 2.

The organisation has a structured innovation process for NPD projects, which has all the elements that the literature appoints. The projects at SBT are managed on costs, which means in this case on hours spent. At the end of each stage, there is a Go/No Go decision and a new budget is assigned/approved. To review the activities within the stages, the assigned hours and the hours spent need to be compared. Unfortunately, the setup of the budgets is not yet aligned with the hour registration, which makes comparison impossible.

An alternative comparison is possible because SBT clusters departmental activities and embeds them in their stage gate model as well. Clustering is universal over all their NPD projects and shows which departments are involved at what stage. Their involvement is based on the needed output at the end of each stage. Figure 2 gives an overview of the departmental activity.

In Figure 4, the hours per department are put against the SBT process model.

This figure shows that all the departments are already involved at stage 2 and 3, which does not match the distribution of the departmental activities in Figure 2. However, the activities of department SD should occur at stage 5, but most of them occur at stage 6A and 6B. Furthermore, the activities of department A&L are most spent at stages 2 and 3, but should occur at stage 4 and 5.

Figure 4 shows a difference between the clustering of activities at SBT and the actual clustering. This can be related to step 1 and 2. For example, the portfolio board allocates resources at

Table 3: Stage-Gate at SBT compared to Cooper (2008).

| Stage | SBT Stage Gate System | Stage Gate System (Cooper, 2008) | |
|---|---|---|---|
| 1 | Market needs and business perspectives | 1 | Scoping |
| 2<br>3 | Feasibility Study<br>Project Planning and Commitment | 2 | Business case |
| 4<br>5<br>6A<br>6B | System Specification/Requirements<br>Preliminary Design<br>Stable Design<br>Stable Design (incl. Prototyping) | 3 | Development |
| 7 | System Validation | 4 | Testing & Verification |
| 8<br>9<br>10 | Initial Launch<br>Series Launch<br>Project Closure | 5 | Launch |

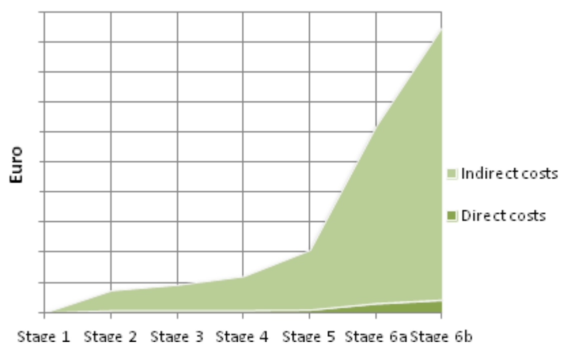


Figure 5: Direct and indirect costs at each stage.

stage 3, but taking figure x into account, the allocation already happened.

### 5.4 Quantify Model

A straightforward cost allocation method is used. Typical for an R&D organisation, most costs occur from labour hours. All indirect and direct costs can be summed up and allocated to a single cost pool. In Figure 5, the total cost of one of the projects is calculated by adding all the direct and indirect costs.

The figure shows that the total costs are largely build up out of indirect costs. For one of the projects this percentage is as high as 96%. It can be expected from a R&D organisation that most activities involve labour hours. The amount of hours spent, which we used in step 3 as a review of the clustering of activities, is in line with the allocation in figure X. Also, it indicates that the labour rate has a great influence on the cost of a project. Using step 1, 2 and 3, potential threats for the labour rate can be assessed.

By demonstrating the BMM4R&D, we did a quick scan of the current situation at SBT. Furthermore, at every step we showed the possibility to evaluate possible scenarios.

## 6 CONCLUSIONS: A BUSINESS MODELLING METHOD FOR RESEARCH AND DEVELOPMENT

In this paper, we built a business model for a research and development organisation. To achieve this, we further specified the business modelling method (BMM) (Meertens et al., 2011), to align it with characteristics of research and development (R&D). This led to the BMM4R&D: a Business Modelling Method for Research and Development organisations. The case studies for the field of R&D illustrate that it is possible to tailor the BMM to specific needs, as was originally proposed.

### 6.1 Academic and Business Contributions

Our main contribution is the demonstration of how the BMM can be tailored. Using the design science approach, we deliver a level 2 artefact (Gregor & Hevner, 2013), namely the BMM4R&D. It is a tailored specialisation of the BMM The approach that we used to tailor the BMM, improves the usability of it for specific fields. The approach consists of attaching applicable, field-specific methods to the available hooks (steps) in the BMM. This opens the way to tailoring the BMM to other fields as well, so it can be used in practice.

The business contribution of this paper is threefold. First, we define a set of characteristics for R&D. Second, we provide a method to create business models for R&D organisations: the BMM4R&D. Third and final, we provide two cases where a business model shows the value of R&D. These all add to the relevance of this paper.

### 6.2 Limitations and Further Research

As part of this design science research, we built a business model for an R&D organisation, using two projects as cases. This demonstrates the use of the BMM4R&D. To evaluate this new artefact further, it should be applied to more cases. Additional case studies could come from within the same organisation, but also from other R&D organisations, especially in other industries.

We tailored the BMM for R&D; however, we advocate that the BMM can also be tailored to other fields (Meertens et al., 2011). The originally proposed BMM has several hooks where different methods may be attached. Thus, tailoring to new fields is easy to do. Yet, finding out which methods are most suitable for a field is a harder challenge.

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# Exploring Invention Capability

Vaughan Michell and Rajeth Surrendran
*University of Reading, Whiteknights, Reading, United Kingdom*
*v.a.michell@henley.ac.uk, rajith.surendran@gmail.com*

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Abstract: Research on invention has focused on business invention and little work has been conducted on the process and capability required for the individual inventor or the capabilities required for an advice to be considered an invention. This paper synthesises the results of an empirical survey of ten inventor case studies with current research on invention and recent capability affordance research to develop an integrated capability process model of human capabilities for invention and specific capabilities of an invented device. We identify eight necessary human effectivities required for individual invention capability and six functional key activities using these effectivities, to deliver the functional capability of invention. We also identified key differences between invention and general problem solving processes. Results suggest that inventive step capability relies on a unique application of principles that relate to a new combination of affordance chain with a new mechanism and or space time (affordance) path representing the novel way the device works, in conjunction with defined critical affordance operating factors that are the subject of the patent claims.

## 1 INTRODUCTION

Invention concerns the creation of new or novel technology (Arthur, 2007) by an act of insight that yields new structures of prior knowledge and experience (Ruttan et al., 1959). As Arthur (2007) asserts "a technology is a means to fulfil a purpose through some effect" and relates to structured objects and their architecture as well as the process of know-how and sequence of activities to do something. Most invention research focuses on strategy and process conditions for company based group invention (Giuri et al., 2007). It suggests invention ability is widespread and invention is driven by market opportunities. A third of European inventions are created by independent inventors (Scherer, 1982) motivated by personal satisfaction, and prestige (Giuri et al., 2007). But, there is a lack of research to explain the process of invention for the individual inventor, what capabilities are required and what activities relate to the unique characteristics of the invented device. This leads to our research question: what is the capability of invention? We explore this from both the agent and device perspective; a) *what are the abilities and process required of the inventor as agent (invention process capability)* and b) *what specific capabilities make an advice an invention?*

### 1.1 Capability

Capability research has traditionally used Grant's definition of a firm's ability to produce a discrete productive task repeatedly (Grant, 1991) and higher level organisational dynamic capabilities (Winter, 2003), rather than functional capabilities. To answer our research questions, we propose functional capabilities need to be defined in terms of agent actions on resources. Business capability can be defined as "*the potential for action to achieve a goal G via an action/series of actions in a process P resulting from the interaction of 2 or more resources, in a transformation that produces business value for a customer*". (Michell, 2011). Capabilities for agents acting on objects can be modelled using Gibson's affordance theory where affordances are; "the property that the environment or physical system offered the animal to enable a possible useful transformation for the benefit of the animal" (Gibson, 1979). Affordances refer to descriptions of (verb-noun) object abilities such as "a cup affords drinking" or an invention such as a thermometer affords temperature measurement. Human affordance, the ability of an animal or agent to complement the object affordance, is termed effectivity (Greeno, 1994). For example "can fish", or "knows how to fish" etc.

Effectivities refer to human abilities, functional skills and knowledge (Michell, 2013). The Wright brothers effectivity of know-how about flight enabled them to invent the first flying aircraft. Our earlier papers showed how capability can be modelled as a process of object affordances and human effectivities of the agents involved (See Michell, 2014). So the capability of invention depends on the process of human activities and effectivities and the invented device affordance that meets novel invention criteria. To model invention capability we must investigate a) Invention behaviour –what effectivities - skills and knowledge are involved? b) The invention process - what activities are involved? c) Invention device development - what constitutes an invented device?

This paper proposes an integrated model of invention capability using findings from primary research on invention behaviour and blending it with models of invention using the capability affordance model. Section 2 explores the characteristics of an invented device. Section 3 explains the pilot survey and the resulting effectivities or human capability traits of invention. Section 4 explores the current work on invention process and problem solving and proposes an integrated model based on this data. Section 5 investigates affordance and organisational capability models and how these can be used to understand invention device capability and contribute to the integrated invention capability model Section 6 Concludes with further work.

# 2 INVENTION CHARACTERISTICS

## 2.1 Device Capabilities

The newness of an invention relates to the idea/model for how something is done before it is known or used by others (Pressman 2014). Patent requirements for legal acceptance and classification of new technology refers to a new "inventive step" within the novel idea. Inventive step relates to a specific 'concept' that is not obvious to those skilled in their knowledge of existing technology in the domain (Cohen and Levinthal, 1990).

Achieving novelty requires an excellent understanding of principles (Williams, 1990), as Arthur (2007) asserts "a novel invention technology must use a new or different base principle to achieve a specific purpose". A principle is a generic explanation of the causal conditions necessary to reproduce some observed natural happening or phenomenon. It describes generally how the invention works and is independent of specific structure and means. For example a set of objects a, interact in situation b producing an effect c resulting from their specific interaction properties. An example phenomenon is mercury expands and contracts according to ambient temperature. The related principle is the height of a column of mercury exposed to the air corresponds to the air temperature. The effect relates to the end state produced as a result of the phenomena acting on an initial state ie the column height rises/falls. Principles explain the how an observed phenomena is harnessed to produce the desired beneficial effect (Arthur, 2007). Arthur's definition of invention "the exploitation of some effect as envisaged through some principle of use" identifies that an invention typically uses a natural effect or result of a natural law through some principle". However, for invention the general principle must be harnessed in a specific arrangement in what Arthur (2007) calls a "working concept", ie how exactly the principle could be applied in practice and be made to cause the desired effect. It refers to how the invention works via generic structures and the generic process sequence of its operation. The process of inventing involves the investigation and testing of a range of possible concepts and component variables, until the right generic combination is identified (Arthur, 2007). In a thermometer the working concept involves the use mercury (ie a high co-efficient of expansion) in a container such that its change of height is easily visible and measurable. Experiments and trials suggest the need for a sealed evacuated tube and what size and shape and how to calibrate it.

The invention concept needs to be organised in a specific physical structural arrangement, ie an architectural system of components,that are proven to produce the specific desired effect. The architecture will cover the spatial arrangements, volumes, part relationships, materials and physical properties and any critical numerical factors that are needed for the invention to work within the specified range of the need or requirement. Harnessing the principle requires development of a technology ie the system of components in a specific architecture form as a device or machine configured for a specific purpose. For a thermometer the device architecture is rudimentary; a known volume of mercury is constrained in a sealed transparent evacuated cylinder, whose height at a known temperature is measured and recorded for different temperatures on a scale beside the cylinder.

Hence an invented device concerns a new specific architectural arrangement of components that interact under some new principle that governs the component interaction to produce a desired effect that achieves some specific purpose. This may be an arrangement of physical parts or of people and technology. Arthur's work (figure 1) proposed the knowledge artefacts sequence necessary for invention. However, what are the specific human capabilities (effectivities) and actions required for invention?

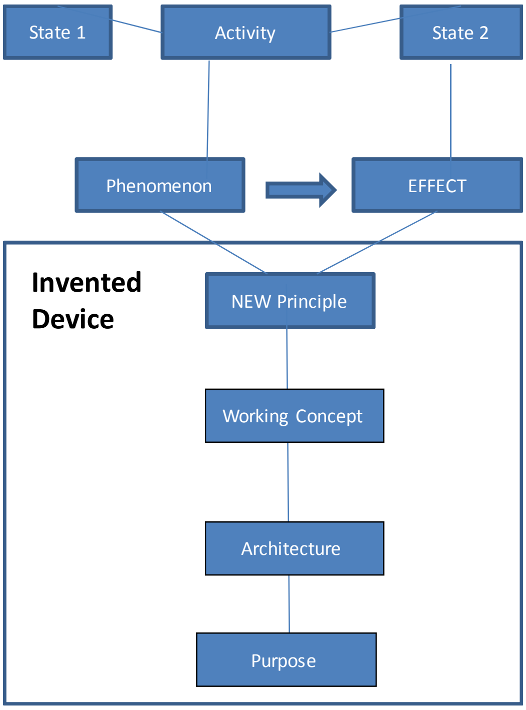


Figure 1: Characteristics of an invented device (adapted from Arthur).

## 2.2 Pilot Survey

A pilot survey was conducted to investigate invention behaviour factors. A sample of seven independent inventors was selected from contacts with the British patent office, qualified by the fact that they had all patented devices in the international patent classification sector of human necessities ie basic devices. These devices included, a sash clamp frame for installing windows, a garden leaf grabber, a non-slip builders bucket for roofers, a wind up generator used in a radio, card readers and displacement sensors and a " Squeezeopen" easily removable lid.

Invention advisors; a patent agent, patent PR agent and a patent advisor were also interviewed. A semi structured questionnaire (Cummins & Gullone, 2000) was based on a literature survey of invention processes and included 90 questions on; the personal factors affecting invention, the steps of the inventive process and the impact of information and knowledge. The questions used a 7 point Likert scale of agreement/disagreement levels (Cummins & Gullone, 2000).

Table 1: Pilot Survey Invention Traits (effectivities).

| | | Level of importance to invention: 1 not important, 7 very important | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | FACTORS | IF1 | IF2 | PA1 | IN1 | IN2 | IN3 | IN4 | IN5 | IN6 | IN7 | | median | mode |
| 1 | Creativity | 6 | 6 | 6 | 6 | 5 | 7 | 7 | 7 | 7 | 7 | | 6.5 | 7 |
| 2 | Curiosity | 6 | 6 | 6 | 6 | 7 | 7 | 6 | 7 | 7 | 7 | | **6.5** | **6** |
| 3 | Childhood exp. | 6 | 6 | 6 | 7 | 7 | 7 | 7 | 6 | 2 | 7 | | **6.5** | **7** |
| 4 | Deprivation | 6 | 6 | 7 | 6 | 7 | 2 | 6 | 2 | 4 | 6 | | **6** | **6** |
| 5 | Imagination | 7 | 7 | 7 | 2 | 6 | 7 | 6 | 7 | 6 | 7 | | **7** | **7** |
| 6 | Inspiration | 6 | 6 | 6 | 6 | 7 | 7 | 2 | 7 | 6 | 7 | | **6** | **6** |
| 7 | Expertise | 1 | 6 | 5 | 2 | 3 | 4 | 4 | 5 | 6 | 5 | | **4.5** | **5** |
| 8 | Self drive/motivation | 7 | 6 | 6 | 6 | 7 | 7 | 6 | 6 | 7 | 7 | | **6.5** | **7** |
| | KNOWLEDGE TYPES | | | | | | | | | | | | | |
| KH | know how | 6 | 6 | 6 | 7 | 7 | 7 | 6 | 6 | 7 | 5 | | **6** | **6** |
| KY | know why | 5 | 6 | 7 | 6 | 4 | 5 | 6 | 6 | 3 | 5 | | **5.5** | **6** |
| KW | know what | 6 | 6 | 6 | 5 | 7 | 6 | 6 | 6 | 6 | 4 | | **6** | **6** |

# 3 INVENTION EFFECTIVITIES

## 3.1 Human Traits

Survey results identified the importance of 16 invention skills and 3 knowledge capabilities. The subset of capability factors are shown in table 1.

Curiosity, the ability and motivation to want to know more, was quoted by most respondents as vital to problem perception and the process of identifying that the need is not currently met or not met well that helps motivate the invention process. Self-motivation was seen as a driver to move the inventor to explore the problem. The ability to deduce an implication from a set of facts, an experience or the act of reasoning, is a sub process of problem solving (Aamodt, 1991). Answers to open questions, suggested inference was important to the invention step, to conceive and consolidate a final working design by connecting the principles and concepts to a working architecture arrangement of a prototype.

Respondents also identified inspiration in driving curiosity into action, to understand and solve the problem in a new way. For example "it is the inspiration of an event that led many inventors". The builders bucket was inspired by the problem of buckets of water and mortar falling off roofs. An inventor was inspired to search for an easy opening jar cap solution for his arthritic grandmother as none were available. Hence a need coupled to a gap in the available devices to meet the need is a key driver or invention.

Expertise or existing knowledge in the area was not felt to be so important with respondents suggesting "expertise can constrain creativity and thought processes necessary for invention". However, knowledge of engineering and problem solving subjects was felt to help by a number of respondents. This is supported by Cohen’s absorptive capacity principle suggesting prior problem solving knowledge and experience better enable the acquisition of new problem solving capabilities (Cohen and Levinthal, 1990). But a careful balance is needed between what Arthur calls "knowledge of functionalities" ie the principles of how things work and problem solving, and a creative mind open to new concept combinations.

Respondents felt imagination to be critically important, relating this to an ability "to see their ideas in 3D in their mind", that helped them create and identify solution options. Mental models or the ability to create often a dynamic model of ideas and mechanical/electrical action representations are important to the ability to invent (Ash et al., 2001). Equally important is the inventor’s ability to evaluate and categorise experiences and concepts, through the use of reference frames or mental data structures which links to attributes and values (Ash et al., 2001). Unsurprisingly, creativity was seen to be vital to an inventor’s ability "you cannot solve an inventive problem without being creative". Creativity, "the ability to think what no one else has thought on seeing the same event", (Swann et al., 2005) is vital in the solution exploration stage. Patent agents felt creativity is necessary to work around existing inventions and produce the inventive step.

## 3.2 Knowledge for Invention

The capability to invent is heavily dependent on the inventor knowledge base and the ability to learn, assimilate and apply new knowledge (Büyükdamgacı, 2003). There are three primary know ledge types Know how, why and what.

Know how relates to procedural knowledge based on learning by doing ie practice and feedback or first-hand experiences applying facts from experience. Know how is cumulative and dependent on the path of prior experience gained (Arthur 95, Levitt and March 1988). For example the Wright brothers were able to use their bicycle know how to develop and test the wright flyer mechanics and create flying know how from their tests (Weber, 2006). Know how relates to the "doing, using, interacting" (DUI) mode of learning and innovation (Jensen et al., 2007). Know how is critical in the solution and prototype investigation stage of invention to assemble and try out possible concept architectures and test how well they meet the need. Know how was identified as most important by almost all respondents. This is to be expected as low technical complexity inventions are often created by trial and error know how (Dutton & Thomas 1985).

In contrast, Know why knowledge is based on understanding of principles and theories. It is the process of knowing through analysis or primary experience or second-hand information to identify causal rules about why something behaves as it does in terms of logic, natural laws etc (Garud, 1997). Know why is cumulative, depends on prior knowledge and the ‘bi-association’ of new knowledge from different areas to develop new theories and knowledge (Garud and Nayar 1997). Know why was seen as less important than know how. Using know why for modelling is referred to as science, technology, innovation or STI model of knowledge management (Garud, 1997). It enables inventors to use models to calculate more precisely how a principle can be converted into a prototype concept that is more likely to produce the desired effect. For example, the Wright brothers used weight and lift calculations to determine the required engine power (Weber, 2006). Know why can minimise the number of prototypes and experiments and avoid missing the inventive step that meets the need. This is critical as many inventors take years to search and try out invention prototypes in an effort to discover the application of a new working principle. Know why replaces the serendipity/chance of the lone inventor who otherwise relies on know how to try prototypes with different variables and to adjust them to a solution. Patent advisors suggested know why was less important at the discovery stage of invention, but know why relates more to defining claims of the inventive step, possibly because know how trial and error is easier and low cost within the invention category analysed and know why, in terms of inventive step, definition can be established via the patent agent.

Know what is based on declarative knowledge) and is generated by learning by using (Rosenberg 1982 ). Know what was felt to relate to ‘expertise’ in known facts which was seen to be moderately important, but less critical than know how.

In summary survey respondents suggested the invention process begins with inquiry or curiosity as to why a problem exists. Then inspiration fosters a drive to solve a problem is based on a problem experience often connected to a driver eg personal or family need for solution that makes the problem important. This is followed by imagination and creative ways to solve the problem that prompts serious investigation activity to experiment and test potential prototypes against the need. Respondents suggested the inventive step is characterised by a moment of inference or insight to see a potential solution among possible variations in tested prototypes that depended on an ability to synthesise knowledge. The final steps involve evaluation and interpretation of the inventions importance, value and why it works, codified into a patent. The results can be interpreted as the sequence of effectivities required for invention, but not the activities. For this we used insight from process model research.

# 4 INVENTION PROCESS ACTIVITIES

## 4.1 Process Review

Invention is seen as a needed problem solving process using "a problem description, a goal and a knowledge base as input and derives a solution that satisfies the goal" (Büyükdamgacı, 2003). The widely used information processing model for problem solving identifies 3 steps; perceiving the problem in the "task environment", converting this into a problem space or mental model of the observed problem and then a solution space of possible solutions based on the knowledge and memory of the problem solver. These process steps are heavily influenced by the prior experience of the inventor.

Inventing is also a creative process. Isaksen & Trefinger's 60 year old creative problem solving methodology (Treffinger et al., 2008) identifies three key creative stages. Firstly understanding the challenge involves identifying problem solving opportunities, gathering appropriate data about the problem and importantly framing and identifying the right problem. Identifying the right problem is key to reducing the invention search space and hence increasing the chance of finding the application of the right principle in a working concept (Weber, 2006). The second stage focuses on generating solution ideas. The final stage, developing criteria for and selecting and testing solutions and techniques for building acceptance of the proposed solution (Isaksen and Treffinger, 2004). Their process highlights the need to clearly identify and define the problem. This is emphasised by the Wright brothers division of the problems of flight into lift, power and finally control with the focus on 'how' to warp the wing (Weber, 2006). It also identifies a critical balance between thinking creatively and a further effectivity – evaluation and judgement of solutions.

Usher outlines 4 steps for invention. Perception of the problem that relates to an unsatisfactory method of meeting a need, followed by setting the stage to gather data regarding the problem and possible solutions, followed by an act of insight (confirmed by respondents ) and critical revision to the final solution (Ruttan, 1959).

Exploring a problem and separating it into problem exploration and solution exploration stages is critical for technical problem oriented engineering (POE) problem solving methods (Hall and Rapanotti, 2009). Whilst TRIZ, the theory of innovative problem solving developed to help inventors identify combinations of parameters for a new ie inventive solution, emphasises the need to synthesise and evaluate the newness and feasibility of the solution (Barry et al., 2010).

## 4.2 Proposed Invention Process

Integrating these process activities with the effectivities and Arthur's model yields the proposed process necessary for the capability to invent, with the required human effectivities defined as per the process in our earlier papers (see table 2).

### 4.2.1 Invention Need Identification

Survey respondents suggested invention begins with "think (ing) of a problem" However as we have seen the problem that leads to an invention has a specific need to do something differently. This involves establishing that the current way of doing things does not meet current need as evidenced by survey respondents. Critically unlike normal problem solving, for invention there must be no immediately obvious alternative means of solving the problem.

### 4.2.2 Problem Definition

For efficient invention clarity is required about the correct problem to solve (the "goal" of POE) and the invention requirements or need (cf Isakson's problem framing). This is illustrated by the Wright brothers clear definition of lift, power and control problems and requirements which allowed them to focus their resource costly efforts more productively than rivals. Similarly, the jet engine inventors Whittle and Von

Ohain were both able to express an informal need in a set of defined technical problem requirements that optimally directed their inventive search (Arthur, 2007).

#### 4.2.3 Problem Exploration

However, most inventions involve the evolutionary recombination of existing technologies (Fleming and Sorenson, 2001), or principles. So a novel invented solution requires an understanding of existing solutions and what does and does not work (know how). Most inventors see the need to explore and fully understand the problem, its cause and the factors involved ie as in Isaksen's "stage setting". For example respondents suggested "I immerse myself in a challenge and learn as much as I can about it". Clearly identifying the importance of problem-context understanding.

#### 4.2.4 Unique Solution Exploration

The move to a solution involves searching for possible new architectural arrangements of principles that meet the defined requirements. Unlike traditional problem solving, this is not any, or a well tried solution, but one that uses existing principles and concepts differently in a new way. Narrowing down ideas can involve trial and error experiments by taking a principle and trying it out in concept form until a working concept is developed that meets the invention needs (Arthur, 2007). All respondents confirmed the importance of "building a prototype and developing and testing the concepts".

#### 4.2.5 Invention Synthesis & Evaluation

Filtering ideas into a working concept is also critical. A respondent suggested "inventors have an uncanny ability to generate ideas and narrow down the best idea from them" and others that their process involves; "filtering the ideas and (then to) prototype the best idea, refine it and patent it", suggesting synthesis and evaluation as advocated in Bloom's learning taxonomy (Starr, 2008) are key inventive skills or functionalities. It is in the combination of trying and inspecting combinations of principles that many respondents suggested the "Eureka moment" of the elusive inventive step was hidden. Respondents described the "flash of inspiration that enables inventors to see a solution to a problem". This relates to the inference and reasoning task of identifying how known principles could be integrated into a concept, able to meet the problem need (Cohen and Levinthal, 1990). Thus we propose the inference and synthesis combined with evaluation, using invention domain knowledge delivers the inventive step.

#### 4.2.6 Invention Design

What Arthur refers to as a working concept needs to be refined to a robust solution that reliably meets the requirement parameters. This involves identifying and optimising the parts/components of the invention architecture to meet the desired need. A respondent suggested "in my process; I refine it (the invention) and patent it". Refining is an engineering design activity that requires careful and detailed specification and testing of all parts of the invention and their physical properties and behaviours to meet the requirement tolerances. It is also necessary to identify the inventive step claims necessary to patent the design as a new application of principles and concepts to meet a specific set of uses.

## 5 INVENTION AS NOVEL DEVICE CAPABILITY

### 5.1 The Capability Affordance Model

We now turn to objective b): what specific capabilities makes a device a new invention, or what is device invention capability. Our previous papers used affordance theory to model device capability and we apply this to identify invented device capabilities. The capability-affordance model at the action or atomic level is based on the concept that the capability of an agent or device can be decomposed into an affordance cause and effect mechanism operating through a topological path "*The affordance mechanism is the cause and effect energy transformation at the interface between the two or more interacting resources and its properties that enable the transformation*" (Michell, 2014). The causal path relates to the space-time path of how the agent, the device and it components change and move as energy transfer propagates through the connecting objects. The capability of a device to perform a specific action is then a combination of an energy mechanism (either within the device or supplied by an external agent) acting through a path defined by the structure and architecture of the device. The path may be a series of linked affordances or an affordance chain (Michell, 2014). The affordance chain identifies the individual interactions or actions between object interfaces as they interact. The critical affordance factors (CAF) quantify the range of values over which the device will deliver the capability and is a generalisation of Warren's work (Warren, 1984).

In the thermometer example the mechanism that makes the device work is an affordance chain of heat transfer from the atmospheric surroundings through the glass tube to the mercury which is channelled by the path constraints of the evacuated thermometer tube that forces the mercury according to its physical expansion properties to rise up the graduated cylinder when the ambient temperature increases. Hence a sealed evacuated mercury containing cylinder 'affords' measuring temperature changes. The CAF for the thermometer would include a max/min temp range for accurate measurement and failure ie temperatures beyond which the glass will break or materials or the required properties fail.

## 5.2 Capability Mechanism

The capability affordance model relates to Arthur's model of invention. For example, the leaf grabber invention uses a principle of the lever, with a working concept of opposed arms with large rake jaws. However, to qualify as a new invention the specific way the architecture works or dynamically causes the desired effect must be different. Ie what Arthur calls the principle ('an effect in action'). The principle refers to the chain of interactions or affordance chain that relates to a cause-effect. It can be decomposed using the CAM model to the causal mechanism and path. Where affordance relates to a property or function of the object that satisfies a need. Most of the chosen inventions eg bucket, grabber have short affordance chains ie energy derives from a human agent to a single action. Although the sash clamp has many interacting affordance chain components, it is too complex to illustrate here. For the leaf grabber invention the affordance mechanism involves human energy forcing the arms together through a constrained path (dictated by the invention architecture) as the jaws rotate about their pivot to trap the leaf waste. The squeezeopen cap mechanism also requires a human energy (mechanism) to deform it to enable it to be removed.

However some inventions rely on a new specific mechanism as well as a unique path. For example the crank powered generator connected to a rechargeable battery is the basis of the patent claim in the electric current generator (Baylis 2001) and defines a new general principle for a clockwork DC power mechanism architecture. It uses an affordance chain of human energy being transferred to the clockwork mechanism which is then released and moderated via an electronic controller to power a device eg radio.

## 5.3 CAM Interpretation: Path

For invented novel devices, the path, ie space time way the device works, must be different from existing devices ie "the topology of (component) interactions is unique" (Williams, 1990). This relates to the affordance path topology and suggests for an invented device the specific path followed by the device components as they deliver the capability to meet the need of the invention must be new. Specific path topology is seen in the squeezeopen cap, where the path affordance is based on an affordance chain mechanism of human force that deforms a specific type of plastic cap such that it slips easily over the specifically designed (path constraints) rim and can be removed with minimum force. The patent claim directly illustrates this path affordance by legally describing the specific space time path followed to remove the lid and its relation to specific architecture. For example "claim 3, in which the side wall of the lid has a bead portion for sliding over the formation during the initial separating movement of the lid from the body portion" (Sheahan M. 1999). Five of the inventions surveyed relied on similar unique path topology and device structure. For example the leaf grabber uses opposed leavers – a well-known standard mechanism of magnifying force, but the critical affordance factors are the shape and arrangement of the jaws and their length provide a way of working or path that is deemed to be unique.

## 5.4 Critical Affordance Factors

Critical affordance factors relate to device parameter values and limits for which the capability is possible. These factors relate to both mechanisms, ie forces and to path dimensions, eg size of components. They also relate to the physical properties of the materials that ensure specific mechanism and path behaviour. For the squeezeopen cap example, the path relates to the architecture dimensions of the deformable cap interacting with a specially designed lip, under a specific amount of force, otherwise the cap would not work as intended. The invention claim specifies the specific cap material that has the properties to deform the right amount (based on specific affordance parameters) under an old persons' hand pressure, given the designed geometry between the cap and jar. The leaf grabber depends on the arms and size of the jaws being a specific size etc. See figure 3.

Hence any invention must and does include clear specification relating to any new path and/or the energy transfer mechanism and the specific (capability affordance) factors and their range values

Table 2: Processes Related to Invention.

| Process | Problem side | Solution side |
|---|---|---|
| P0 Pilot Survey | curiosity → inspiration → imagination | investigation → inference → interpretation |
| P1 Usher | Problem perception → Stage setting | Act of insight → Critical Revision |
| P2 Information processing model | Task Environment → Problem Space | Problem Solution |
| P3 Isaksen | Understanding the problem: Problem finding, Data gathering, Problem framing | Solution idea generation → Solution Development |
| P4 POE | **Problem Exploration (vs goal)** | **Solution Exploration & Validation (vs goal)** |
| P5 Creative Problem solving (Lumsdaine) | Problem identification → Problem data collection & definition | Solution idea generation, Solution synthesis, Solution evaluation, Solution implementation |
| P6 TRIZ | | Solution idea generation → Solution synthesis → Solution evaluation |
| **Integrated Invention Process** | **Invention Need Identification**, **Problem Definition** | **Problem Exploration**, **Unique Solution Exploration**, **Invention synthesis & Evaluation**, **Invention Design** |

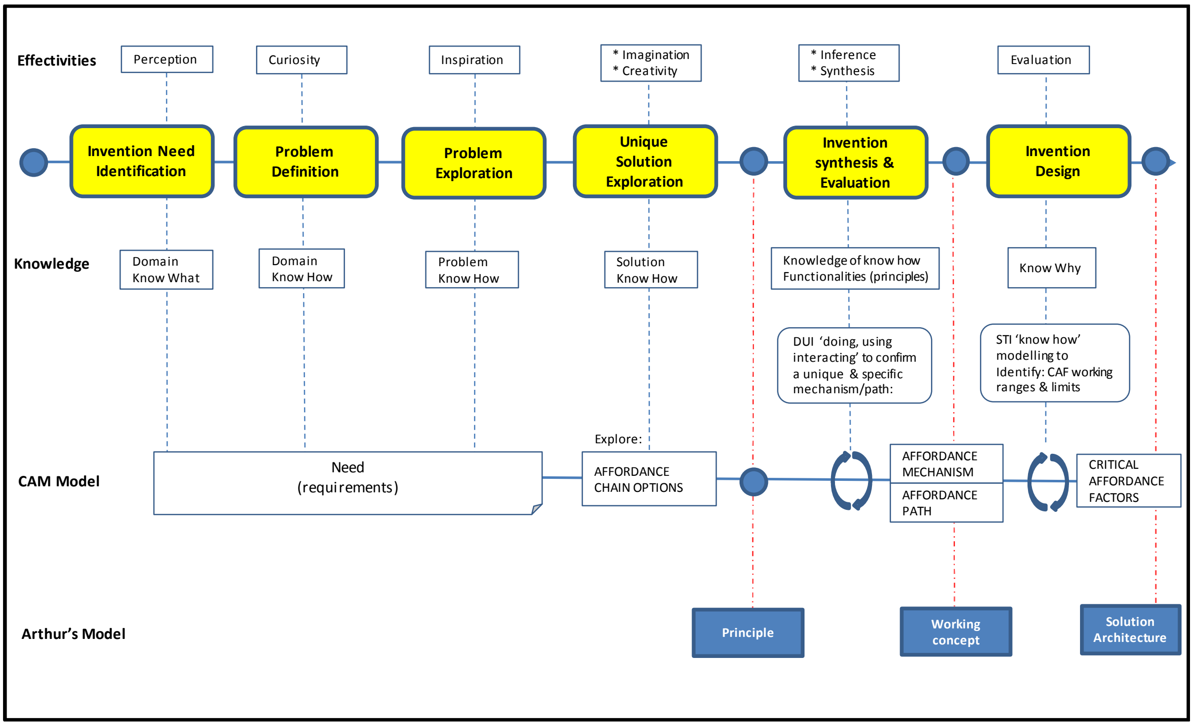


Figure 2: The Invention Capability Process.

over which the invention will work and hence legally what must is protected by the patent.

In terms of invention process, a knowledge of Arthur's principles, or causal mechanisms and various architectures and paths that inventions operate in is gained and used in the solution exploration invention activity.

The solution exploration stage is where the inventor explores the possible principles that could be used to meet the need. Where the principles are affordance chain compositions. For example Whittle's exploration of combinations of power unit mechanisms in different affordance chains such as "rockets, turbines driving propellers or rotating nozzles, fans powered by piston engines etc" to invent a new aircraft power plant, the jet (Arthur, 2007).

The development of a prototype, in the invention synthesis and evaluation stage, relates to testing of different architectures to identify the working concept. Prototype testing involves empirically trying various mechanisms and path variations to identify a different way to existing solutions. Finding a new working concept embodies the inventive step which defines a new and previously undiscovered specific mechanism and a working path/architecture that delivers this need.

The final invention design stage; solution architecture involves establishing the optimum arrangement of components for the invention. This includes exploring and identifying the limitations to its workings, ie establishing and quantifying critical affordance factors ie the range of values relating to the way the device operates. This involves critical dimensions, characteristic values and physical properties needed. For many inventions formal requirements are often only produced, to qualify the legal patent limitations, after thorough testing of the prototype to understand its working limitations at which the critical affordance factor values are exceeded.

## 6 DISCUSSION & CONCLUSIONS

Based on empirical findings and analysis of theory we reason that a) 8 necessary human capabilities or effectivities are required for individual invention capability. We also propose 6 key activities that require these effectivities and are components of the functional capability of invention. We have identified different types of knowledge at each stage and key differences between invention and general problem solving processes at the need identification, solution synthesis and solution design stage. We have shown b) what specific capabilities makes a device a new invention. We observed that inventive step capability relies on a unique application of principles that relates to a new use of mechanism and or space time (affordance) paths representing the new way the device works, in conjunction with specific and defined critical affordance operating factors that enable the invention to meet the invention need in a given operation envelope and that these are used to legally specify the inventive step.

Complete details of questions and examples have been limited by space. The research is also limited by only studying ten invention cases. To reduce bias we are currently working on a larger sample and statistical approach to corroborate and evaluate the relationship between the human traits (effectivities) and process activities necessary for invention capability. We are also evaluating mechanism and path characteristics of other devices to provide further evidence for the capability affordance model.

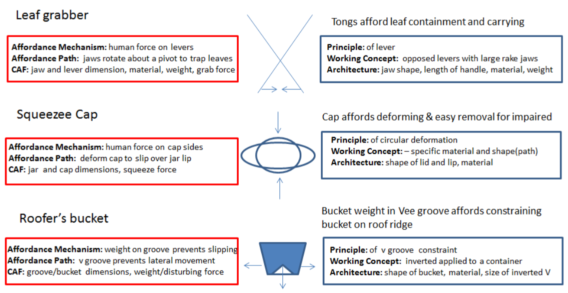


Figure 3: Example Inventions – Mechanism, Path and Affordance Factors.

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# Shaping IT Capabilities to the Business Strategy
## *Capitalizing on Emerging Technologies and Trends*

Ivan I. Ivanov
*Empire State College of the State University of New York,*
*Hauppauge, NY 11788, U.S.A.*
*ivan.ivanov@esc.edu*

Keywords: IT architecture, Enterprise architecture, IT governance, Socio-technical system, Systemic effect, Emerging technologies, Cloud Computing, Mobile Computing, Consumerization of IT.

Abstract: IT progressively has evolved providing greater opportunities to optimizing business processes and to enabling new business models and services. The fast pace of IT advancement drives considerable prospects for business improvement and growth. The strategic alignment of IT capabilities to organizational business strategy, as content and processes, ensures further IT governance to seize opportunities for improvements and to maximize revenue. Utilizing a well deliberated framework -Operating model, Enterprise architecture, and IT engagement model- the paper explores the impact of emerging technologies on the alignment process. Currently, companies across the globe are going through a very disruptive technology development: Consumerization of IT - when new technologies emerge first in the consumer market and then, after mass acceptance, are employed largely by business organizations. Consumerization of IT, along with workforce mobility, reliable, accessible and affordable remote computing, are forcefully reshaping the corporate IT lanscape, affecting the relationship between enterprise IT, knowledge workers, corporate users, and consumers. This paper confers the impact of these trends on the IT domain and specifically emphasizes on the dynamic forces interlinking IT capabilities with the business agility, growth and asset utilization.

# 1 FRAMEWORK FOR ALIGNING IT TO BUSINESS STRATEGY

Increasingly we have witnessed how business success and economic opportunities steadily depend on IT-enabled capabilities and IT-driven business transformations. In today's global digital economy, the technology and business domains are colliding forcefully than ever and new business models and growing prospects emerge. The IT and especially emerging technologies profoundly change how companies create value both within specific industries, and through industry boundaries.

In order to understand why corporations develop IT architecture, it is important to know their business mindset when doing so, which ultimately begins with a discussion on ***strategy***. Some authors state that strategy cannot be planned, since doing so would suggest a controlled environment. These theorists state that strategy happens in an uncontrolled environment, thus it is more useful to consider it to be ***an art*** or ***tool*** over *a plan*.

## 1.1 Identifying Core Components of Business Strategy

In the 1970s, the strong competition in several key industries (appliances, automakers, and banking sector) up surged a new concern about the business operating environment. The traditional long range planning lost its position to strategic planning, which allowed businesses to consider changes to its surroundings.

Strategic planning forced businesses to look beyond its own walls into the greater fluidity of the ever growing global marketplace. A holistic analysis of the factors related to the external environment – customers and competitors- and the internal environment –the organization- is needed for maintaining finest management practices. According to the online business dictionary "…the objective of strategic management is to achieve better alignment of corporate policies and strategic priorities." "A brilliant strategy or breakthrough technology can put any company on the competitive map, but only solid execution can keep it there." (Neilson, Martin and

Powers, 2010). Through structural changes or efforts focused on performance improvement produce normally short-term gains. Instead, concentrating on the three major sections formulating this process: *Strategic Thinking*, *Strategic Planning*, and *Strategic Momentum* is far more powerful and successful (Swayne, Duncan and Ginter, 2006):

***Strategic Thinking***: This is a stage the organization should grasp both the detailed view of itself -what it does well, and what seems to be lacking, and systematic picture of the external environment.

***Strategic Planning***: First at this phase a situational analysis, based on the first stage findings a SWOT analysis -strengths, weaknesses, opportunities, and possible threats- should be performed. Next steps will include formulating a strategy, and determining ways of its implemention.

***Strategic Momentum***: The final stage should evolve the strategic plan implementation. The organization needs to not only keep in mind who has been working towards strategy implementation, but must also keep in mind as well changes in the external environment.

The essence of ***Strategy*** according to Harvard Business School professor and one of the world's most advancing thinkers on strategy Michael Porter is *"about being different,"* which means a company to choose for their core business different and unique set of activities or to perform already known activities in a different way. With a set of activities, different from those of the other competitors in an industry a company winning strategy means creation of "unique and valuable position" on the market. Creating strategy also means making tradeoffs and combing the unique activities to fit well together and reinforce one other.

### 1.1.1 Industry Analysis

Referring again to Michael Porter, the structure of an industry is embodied in five forces that collectively determine industry profitability and should be considered in strategic formulation: Rivalry among Existing Competitors, Bargaining Power of Buyers, Threat of Substitute Products or Services; Bargaining Power of Suppliers; Threat of New Entrants. The shared power of the five forces varies for different industries as does the profitability (Porter, 2008). The model exposes comprehensive outer view of the organization with its traditional direct competitors and the correlation with four other forces within its market environment. The industry analysis framework suggests that industry differences can be analyzed a priori by managers using the Porter's analytical framework, and based upon the results of this analysis, executives can decide whether to enter an industry or forgo investment.

The Threat of New Entrants force represents the extent to which the industry is open to entry by new competitors, or whether significant barriers to entry make it creates comfortable shelter so the existing firms need not to worry about competition from outside. The Threat of Substitute Products or Services force denotes the extent to which the products or services marketed by the company are subject to potential substitution by different products or services that fulfill the same customer needs and expectations. The Bargaining Power of Buyers force signifies the extent to which customers of those organizations in the industry have the ability to put downward pressure on prices, highly concentrated buyers (such as Wal-Mart) and low switching costs typically conspire to increase the bargaining power of buyers. The Bargaining Power of Suppliers force represents the magnitude to which the firms or individuals who sell production input to the organizations in the industry have the ability to maintain high prices. The Rivalry among Existing Competitors force represents the magnitude to which fierce battling for position and aggressive competition occur in the industry. The term *hypercompetition* refers to industries characterized by fierce rivalry among existing firms and very rapid pace of innovations leading to fast obsolescence of any competitive advantage and a consequent need for a fast cycle of innovations. The consumer electronic industry -mobile smart devices in particular- is the most current example, as is the ICT industry in general.

### 1.1.2 Industry Analysis and the Role of IT

Scholars and experts who have embraced industry analysis to search and identify IT-dependent strategic initiatives and opportunities advise to consider information systems effects on one or more of the industry forces, thereby tipping it to the company's advantage or preventing foreseeable losses.

Investment in and the use of specialized emerging technologies and/or applications could raise or increase barriers to entry in the industry. In so doing the existing firms would reduce the threat of new entrants. This particular option is most likely applicable in IT intense and highly regulated industries such as Healthcare, Banking, and Finance.

The widely adoption of Internet technologies, and more specifically products and services searches, e-commerce and online transactions utilization contribute steady to dynamically shifting power away from suppliers, so toward buyers. As much as the Internet based systems and applications help firms strengthen their bargaining position toward either suppliers or buyers, they also could reduce their bargaining power just before either one.

Innovative emerging technology executions by creative companies, whether incumbents or new entrants, could speed up immediate changes into the basic of industry competition. A glaring example of this dynamic was presented by the advent of online retailing in the late 90-ties and early 2000, and later with the individualized entertaining industry.

Essentially advances in the IT are transforming the industry structure and alter each of the five competitive forces, create the need and opportunity for change, hence, industry attractiveness as well.

While Porter's five competitive forces model is truly important when strategic planning and managerial decisions are taken, the impact of the key internal forces clearly associated with the information technology are particularly critical to the operational effectiveness and shapes the organizational business strategy and benefits.

## 1.2 The Sociotechnical Systems Model

Technology has become the heart and soul of every business and it has a powerful effect on competitive advantage in costs optimization, enhancing product and services differentiation, or spawning new business options. Every product on the market has physical and information content and the tendency today is towards increasing the information component of products. Naturally, IT is deeply involved in all aspects of the information component, and yet IT is increasingly involved in the physical component likewise – manufacturing processes become automated, faster, more efficient and precise with IT. The IT transforms the products and affects the overall value activities of an industry. Starting from traditionally information intensive accounting, and continuing to performing optimization and control functions, and furthermore - judgmental, executive decision functions, the significance of IT is becoming ever more strategic for companies' competitive advantage. How to align the IT to the business strategy and to gain value turning the great strategy into a great performance is a "mature way of doing business" in the information age.

To explore the complexity of the problems inside organizations, and to avoid unrealistic expectations when aligning the IT to the business strategy, a formal methodology of examining and evaluating IT capabilities in the organizational context should be applied. In IT, "*capability* is the ability to marshal resources to affect a predetermined outcome" (McKeen, Smith and Singh, 2005). The core IT capabilities are discussed later in the paper and they are critical to meet the enduring challenges of uniting business strategy and IT vision, delivering IT services, and designing an IT architecture.

The contemporary Information Systems approaches incorporate multidisciplinary theories and perspectives with no dominance of a single discipline or model. Gabriele Picolli in his Information Systems for Managers text features IT as a critical component of a formal, sociotechnical information system designed to collect, process, store, and distribute information (Picolli, 2012). Kenneth and Jane Laudon in Managing the Digital Firm, define Information Systems as Sociotechnical Systems incorporating two approaches: *Technical* and *Behavioural*, with several major disciplines that contribute expertise and solutions in the study of Information systems (Laudon and Laudon, 2014).

The notion of above definitions is based on the Sociotechnical theory work developed by Tavistock Institute in London in mid-50s and 60-ties. The IT Sociotechnical approach not only visualizes the concept, but reveals the impact of new technologies and processes –the technical subsystem- on the entire work system, and the dependencies and interactions between all other facets and components of the sociotechnical system. According to Picolli any organizational Information System can be represented as a Sociotechnical system which comprises four primary components that must be balanced and work together to deliver the information processing functionalities required by the organization to fulfill its information needs. The IS Sociotechnical model validates the most important components, and at the same time illustrates primary driving forces, within organizations: structure, people, process, and technology. The first two – *people* and *structure* – shape the *social subsystem*, and represent the human element of the IS. The latter two – *process* and *technology* (more specifically IT) – contour the *technical subsystem* of the IS and relate to a wide range of IT resources and services intertwined with a series of steps to complete required business activities.

The sociotechnical system approach is instrumental in helping policy and decision makers to strategize and manage organizational change particularly by the introduction of a new IT. The easiest to envision, justify and manage change is *automation.* It occurs when an IT innovation modifies existing processes without affecting the social subsystem sphere. Thus, this change requires little executive sponsorship and involvement, while the financial benefits can be estimated with some precision. The further change impacts primarily on the people component of the sociotechnical model. It takes place when the information intensity of the processes being performed is substantially changed due to introduction of new IT. This level of change – *informate* - affects mainly employees and most likely the customers, and would require executive sponsorship and greater management involvement to provide appropriate training and overcoming the human tendency to resist changes while at the same time seeking to take advantage of available market opportunities.

The advanced change incorporates the previously described changes, while also causes organizational structure disruptions. The magnitude of this – *transform* – change shakes all dimensions of inner components interactions: it transforms the way how organization selects, utilizes and manages IT; it results in a change in the reporting and authority structure of the organization; it manifests a novel way of tasks' accomplishment or/and a new set of tasks or processes. The later change requires significant managerial and executive involvement with a steady championship by the top management team for both signaling purposes and to provide the necessary political impetus to complete the transition.

The Sociotechnical system approach not only validates the four critical components of the Information system interdependency, but proves that none of them works in isolation. They all interact, are mutually dependent, and consequently are subject to *"systemic effects"* - defined as any change in one component affecting all other components of the system. "Every business decision triggers an IT event," this quote from 2003 by Bob Napier, former HP's CIO is still valid: when addressing business issues like productivity, service quality, cost control, risk management, and ROI the decision-makers have to consider the appropriate corresponding modifications in the IT domain.

The process of changes and reciprocal adjustment of both technical and social subsystems should continue to interplay and growing closer until a mutually satisfying results are reached. However, the model in reality could not be with equal subsystems' changes. It should grow from micro to macro level to reflect crucial influences of the external environment, including regulatory requirements, social and business trends, competitive pressures, interoperability with partnering institutions, especially when we analyze the role of the IT systems.

## 1.3 Unfolding the notions of Operating Models and Digitized Platform

The process of enterprise architecture design requires a holistic view of the organization. Following such approach makes possible to explore how business processes, information flow, systems, technology and predominantly business strategies and priorities interact and contribute value to the organization. Hence, understanding the organizational synergy in detail provides the means to define two important choices related to the organization's business operations:

- How *standardized* its business should be across operational units?
- How *integrated* its business processes should be across those units?

Any organization operates in one of the four possible operating models, based on the business processes selection as illustrated by Weill and Ross from MIT Center for Information Systems Research in their IT Savvy textbook (Weill and Ross, 2009). Which one is considered as "the right one" depends on the organization executives' strategic decision:

- In the *diversification model* - low standardization and low integration - organizations operate in a decentralized mode with independent transactions, unique units with few data standards across local autonomies, most IT decisions are made within the units;
- The *coordination model* - low standardization, high integration - is used by organizations that deliver customized services and solutions by unique business units, while accumulating and providing access to integrated data across the divisions. The decisions should be made in consensus for designing IT infrastructure and integrated services, while IT applications decisions are processed within individual units;
- Organizations implementing the *replication model* - high standardization, low integration - typically provide high operational autonomy

to their business units while requiring highly structured and standardized business processes. All decisions related to IT infrastructure, applications and services are centrally mandated;

- Organizations operating in *the unification model* - high standardization, high integration - are centralized managed with highly integrated and standardized business processes. The Enterprise IT is highly centralized and all decisions are made centrally.

In the information age, when the business decisions and success depend on the quickly delivered precise information, IT unquestionably needs to serve as a platform for the business operations. For that reason, the Weill and Ross describe the cocept of Digitized Platform (DP) as an "integrated set of electronic business processes and the technologies, applications and data supporting the processes." Therefore the DP becomes a prerequisite to compete in the digital economy and it should be used for achieving growth and profitability.

The Digitized Platform and the Operating Model are multi facets interrelated. First a company needs to have a vision what they want to do (business strategy), and then to think over how IT can help to create a platform to accomplish their vision for progress and profit. Weill and Ross exemplify the IT role in this process "IT can do *two things* very well – *integration* and *standardization*." Integration – delivers data access across a business, while the standardization – reduces variation in business processes and increases quality, efficiency, and predictability in the operations (Ross and Beath, 2011). By identifying what the company wants to integrate and standardize, actually defines its Operating Model. In fact, the Operating Model establishes the objectives and the requirements for the specific company's Digitized Platform.

Let makes this real by illustrating with two examples how two different well-defined operating models bring together specific requirements to companies' Digitized Platforms and benefit them to achieve remarcable success.

In order to support its business strategies to innovate and remain on leading position in the industry, Procter & Gamble (P&G) not only spends 3.4 percent of revenue, more than twice the industry average on innovation, but has created the most efficient and effective utilization of IT by employing a "Diversification" operating model. To accomplish that feat, P&G created Global Business Services (GBS), an internal shared services organization, to provide a base of over seventy common, repetitive, non-unique services for of the company's 250 world-wide units. GBS delivers shared services ranging from core IT systems to advanced collaborative tools that allow researchers, marketers, and managers to gather, store, and share knowledge and information, such as:

- Web 2.0 based social networking and collaborative tools such as PeopleConnect and ConnectBeam allow over 8000 researchers and scientists from inside and outside the company to work together while reducing research and development costs.
- Microsoft integrated services that include instant messaging, unified communications, Microsoft Live Communications, Web conferencing with Live Meeting, and content management with SharePoint. The integrated services help P&G to reduce the time and effort necessary to share data and information between employees and others involved in the company's R&D activities.
- Cisco Systems' TelePresence technologies have revolutionized the company collaborations throughout all 70 major global locations. P&G required Cisco to build individual video studios to particular specifications that portrayed the distinct characteristics of each location, to make users more comfortable and more accurately to reflect the diversity of employees at each location. The TelePresence system helps P&G to accelerate the decision making and faster speed to market, while reduce business travel costs and increase resource utilization.

Obviously, P&G business success is derived from its efforts in product innovation and collaboration, developed and supported by company's constantly evolving digitized platform. The listed above collaborative systems illustrate how well-planned advanced technologies stimulate sharing knowledge, ideas, innovations and support teamwork across company's world-wide spread autonomous businesses.

A further example of a different operating model is the ING DIRECT Bank *replication* operating model. ING DIRECT operates internationally, and it does not offer any tangible product, but predominantly on-line or phone bank products and services. Although the business processes / services in the bank's branches world-wide are the same, there is no need of interaction between the separate offices as they serve primarily local clients. So there is low need of business processes integration. However, the offered services in all counties are identical and by standardizing the core business activities, ING DIRECT establishes a Digitized Platform that includes standard systems and processes which are very easy to replicate. As a result, ING DIRECT implements its systems for weeks only, avoiding any risks and downtime caused by untested and unknown applications, and thus significantly reduces bank's implementation costs, increases its business efficiency and outcomes.

# 2 THE KEY DOMAINS OF AN ALIGNED ENTERPRISE ARCHITECTURE

In general, "… enterprise architecture (EA) is a holistic design for an organization, aligning the current state of IT capabilities, processes, and resources to enable business strategy" (High, 2014). In the Federal Enterprise Architecture document, the CIO Council refers to the EA as the "glue' that ties business and IT strategy together and that allows them to drive each other. The best practice to conceive and manage EA function is by identifying the key domains, specific for every company.

At times, these key architectural domains are shaped with a broader vision in mind and consist of different sub-fields. Randy Heffner from Forrester Research in his report depicted four interrelated facets of EA that provide short- and long-term effectiveness of delivering business technology solutions: business architecture, information architecture, application architecture, and infrastructure architecture (Heffner, 2010 ). In the Common Approach to Federal EA, six sub-architectural domains delineate the types of analysis and modeling that is necessary for an EA to meet stakeholders' requirements: strategic, business services, data and information, enabling applications, host infrastructure, and security (EO of the US, 2012). Peter High in his World Class IT Strategy book illustrates seven facets in cascading logic from strategy to technology: strategic intentions, business context, business value, business process, data architecture, application architecture, systems (IT) architecture (High, 2014). In all three previously described models, and likewise in other not specified here, the two key EA domains are actually: the Business architecture and the IT architecture. And for each of them we may add particular sub-domains reflecting organization's or industry's specifics. Such approach will simplify and will provide better alignment of different architecture life-cycles in some of these domains as well will reflect more precisely diverse business requirements.

Later on, the business of IT will be discussed with emphasis how IT architecture could be designed, built, and utilized more efficient and with greater value for the company. With escalating IT operational costs and the inability to get adequate value from the IT investments, firms are striving to convert their IT from a strategic liability to strategic asset. According many recent surveys from Gardner, Forrester, and CISR most of the IT budgets are spent for keeping the existing applications and infrastructure running. Many firms typically spend over 80% of their IT budget for supporting the existing systems, and the budget for renovation or new systems, if exists, is below 20%. The widely adopted piecemeal approach results in set of isolated systems wired together to meet the next immediate need. And while there are some valuable IT-based products and services in the company IS environment, the organizations find that it takes longer and longer to test and integrate the new patches with the existing systems, increases vulnerability to systems outages, and makes more difficult to respond to changing business conditions. Reversing such company's IT fortunes requires different thinking from the type that "helped" the organization to create its messy legacy.

The current digital economy has introduced urgency around the need to plan and manage IT strategicaly. To succeed in this approach and with the needed business transformations, the management must pursue four activities to ensure that the company generates stratigic business value from IT. These four activities – Commit, Build, Run, and Exploit - constitute the "IT value creation cycle." (Ross, Beath and Quaadgras, 2011).

In recent years, the IT units have professionalized their *Build* and *Run* IT activities by developing service catalogs, calculating and monitoring unit costs, standardizing project methodologies, defining and implementing technology standards, and working with business partners to manage demands. While improved IT *Build* and *Run* activities generate measurable business benefits, they are just the first step in producing sustained business success. Companies that have achieved a reasonable level of maturity in their *Build* and *Run* activities can greatly enhance the strategic value of IT by developing more effective *Commit* and *Exploit* activities and as a result to excel at all four by implementing seamless handoffs from one activity to the next.

*Commit* involves allocating business and IT resources to enact the company's strategic priorities. This requires the firm to articulate its stratigic priorities in terms of its operational requirements and to direct resources accordingly. This activitiy actually demostrates how well the Business – IT alignment works in every company. At the enterprise level, *Commit* can be political challenging as the senior executives have to fix what is broken in their management and the use of IT. In a nutshell, IT and business leaders have to introduce new ways of thinking about and funding IT that would later lead to building a digitized platform. As previously has been difined the IT architecture domain could be consider interchangeable as Digitalized Platform (DP). *Exploit* involes driving additional benefits from existing business architecture and technology capabilities. Effective *Exploit* leverages digitized platforms to continuously improve corporate performance, profitable growth and business opportunities.

The IT unit of the future will not own all *Commit*, *Build*, *Run*, and *Exploit* activities, but IT and business leaders will need to coordinate and balance well all four activities to ensure that the company generates strategic business value from IT. Every company can decide which accountabilities belong inside the IT unit, and which can best be enacted outside IT. Maturing the four IT value creation activities will demand development and coordination of new capabilities, not only in IT but throughout the enterprise. However the firms are not equally successful in harvesting dividends from the advanced IT capabilities, or driving benefits from their digitized platforms.

## 2.1 Directing IT Funding to Strategic Business Needs

The IT funding and investment decisions are important and challenging part of the previously discussed Commit activities since the systems are implemented, they become part of the firm's legacy: their ongoing support requires time and money, their influence and constrains dictate how business processes are performed. IT funding decisions are long-term strategic decisions that implement the company's operating model.

Weill and Ross intense research on multiple IT successful or failed firms' shows that three important factors are affecting the IT funding and investments in any IT-savvy firms:

- *Defining clear priorities and criteria for IT investments* - the operating model of the company defines the business priorities and how it will deliver products and services. The top executives and IT leaders respectively must clarify the IT investments priorities. All companies are different, but what the IT savvy have in common is that they "create a central point for business change efforts" - and this central point helps them to prioritize the IT investments on high-value projects.
- *Establishing transparent process of project prioritization and resource provisioning* - in IT well-advancing companies the senior management is responsible for strategic business initiatives and respectivelly for project prioritization. The prioritization criteria must be clear and must specify how the IT project team will be held responsible for the project outcomes and deliverables. The transparency in project approval will guarantee that not individual or political decisions would influence project's approval, but pure economic and business efficiency.
- *Monitoring the projects through the phase of implementation and afterwards* - only a few companies track their IT projects from the idea –all through putting into practice, including post-implementation. By applying post-implementation projects' review (PIR), companies can obtain valuable information about accomplished outcomes, further to study and improve their IT funding cycle.

There is a splendid example of how British Telecom revamped its IT funding model based on the newly developed business strategy around three lines of business: retail, wholesale, and global services. At that time (2004), BT was running above 4000 systems, and over 6000 IT employees were working on more then 4300 projects world-wide. The new appointed company management examined the existing IT environment and concluded it is not designed for integration or low cost. To endorse IT to be a critical tool for enabling BT's business transformation, the top management established "One IT for One BT" to consolidate the systems environment and to reduce the project portfolio. Actually BT rebuilt the company's project portfolio by targeting the three core business processes: lead-to-cash ("selling stuff"), trouble-to-resolve ("fixing stuff"), and concept-to-market ("innovating stuff"). These three processes defined the key elements of

BT's *unification operating model* and provided the management focus and clear methodology for IT spending and resource allocation. The process for project approval was established very clear: the business unit prepares project case with expected specific benefits, and then the IT unit provides costs, technologies that can be used, and time frame for execution. Special established requirements and options for the level of ROI were adopted. Furthermore, the projects were monitored following approved metrics periodically in ninety-day cycle, and beyond the implementation phase if they generate the expected business ROI. The company succeeded to reduce its total IT costs by 14 percent and to cut the unit cost of IT services while tripling output and doubling delivery speed. The new IT funding processes, aligned well to the company business strategy, helped BT to be transformed from a very traditional and conservative telecom company to a competitive and innovative firm.

Two additional lessons from the BT case could be summarized in:

- the positive effect of the PIR process helps companies to lower the risks of investments by learning from mistakes and best practices from previous projects and to stimulate employees to explore options to maximaze project's profits;
- to create and manage IT project portfolios in order to be able to estimate and allocate properly the company's IT expenditures. The IT Portfolio combines the IT investments (or costs) for existing systems, which cannot be left without maintenance and support and the IT investments for new projects.

The objectives of the IT advancing companies should be to change the ratio *new projects **vs** existing systems* to 40%:60% and to force the company to a new more competitive level.

## 2.2 Building IT Architecture

Once the company takes charge of directing IT funding to the strategic business needs, it is ready for the second component of the *Commit* activities: to build a digitized platform for enhanced business performance.

The IT architecture or the Digitized Platform of a company is the computer hardware and infrastructure, software applications and data which all together provide and support the core business processes of the firm. In today's highly technological world, the DP is a company instrument to achieve an efficient operating model which will guarantee the company long term prosperity and success. According Weill and Ross from MIT CISR based on their extended research around the globe the companies' IT experience of building their DP as a "journey" that can be divided into four stages:

- Stage 1 - *Localizing* – this stage illustarates the dynamic, energetic and innovative approach of any new company or IT unit, when the firm's priority is rapidly grow of new systems or customized solutions as they respond to customer demands and seek to establish their unique proposition. *Localizing* benefits/concerns analysis: the stage helps in local and functional optimization, however it raises complexity and expensive localized IT solutions that respond to instant business needs, and soon alter the stage name as *Business silos* where business processes lack consistency and costs/performance gaps become commonplace.
- Stage 2 - *Standardizing* – firms retreat from the rapid-fire responces and focus on IT efficiencies through technology standardizations and shared infrastructure and resources. *Standardizing* benefits/concerns analysis: the stage succeeds to discipline processes in IT service delivery and investment prioritization, and to achieve IT functional efficiency as to low OpEx and high reliability, however soon after its adoption it limits opportunities and become incapable to meet new strategic needs.
- Stage 3 - *Optimizing* – firms implement disciplined enterprise processes and share data as required by their operating model. *Optimizing* benefits/concerns analysis: in the stage firms define enterprise priorities, invest in core packaged or customized integrated platforms and systems, and most likely accomplish high operational efficiency. In general IT spending is increasing, but not the IT unit costs, the project priorities are established based on enterprise requirements, rather than isolated ROI estimates, however focusing on standardization and integration provides little if any opportunity for innovations.
- Stage 4 - *Reusing* – firms exploring the opportunities to utilize their business processes as reusable components that they customize for new, but related, business prospects. *Reusing* benefits/concerns analysis: in the stage firms achieve *Business*

*modularity* based on synchronized strategic and operational decisions with clear rules, reliable data, and business intelligence tools, these all result in gaining the most of IT capabilities towards assets utilization, new business opportunities and growth.

The successful DP creates a set of reusable IT modules, and the business agility allows the IT advanced companies promptly to address the following four business opportunities:

- empowering the employees with information they need, and optimizing the processes for maximum performance;
- speeding up product/services innovations;
- reorganizing the business processes to meet better the customers and business needs;
- improving merging and acquisition processes for business growth.

If the company strategy to growth is by acquisitioning businesses, the process of integrating the IT infrastructures and information systems of the new and the old structures is often extremely challenging task. That is why many companies choose "rip and replace" strategy to completely change the old IT infrastructure in the acquired firm with their existing DP which already has been proven success.

One great example of a company that has reached the fourth stage of its journey to build advanced DP and successfully reusing it in many differnet ways is Amazon. Initially Amazon business strarted in dot com era as online C2C bookstore. Their strategically evolving IT architecture well aligned to agile business strategy created a successful and growing business. Soon after the beginning, Amazon has expanded the range of selling goods far beyond books, and proffered its advanced wide-spread digital platform to large number of businesses and independent retailers. At present, over 2.5 million retailers are using the Amazon DP and are part of its enormous marketplace with over 150 million global customers Amazon did not stop with the first previously described transformation from direct sales business model to sales-and-service model. The company has capatalized on its advanced IT capabilities and succeeded to build one of the largest in the world cloud computing platform, creating and launching the Amazon Web Services in late 2006. In short, with this new business model, based on innovative utilization of existing DP and enhancing it with new applications and higher computing performance, Amazon targets and serves new customers and different business processes, providing computing resources on demand, and applying diverse profit formula. AWS is an explicit example of IT advanced firm where the investments in IT are used for building digital platform that can be used and reused multiple times by the company itself, its direct customers or resellers to reap the benefits and to enhance the growth.

Evolving through the four stages of building DP is a challenging experience for organizations and their IT units. As it has been said at the beginning - the radical changes impact the organizational mindsets in rethinking and reengineering the traditional IT resources. Indicators for such transformations can be seen analyzing the latest Gartner CIO Agenda Report from 2015. It is based on survey gathered data from over 2500 CIOs from 84 countries across the globe. The results represent how IT domain is moving beyond IT craftsmanship (focusing on technology) and IT industrialization (focusing on process efficiency and effectiveness) into a third era of enterprise IT, where digitalization is transforming business models and provides continual opportunities for growth, innovation and differentiation - Figure 1. (Gartner, 2014).

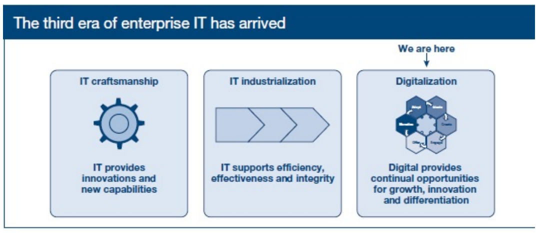


Figure 1: New IT domain - "Digital first" (Gartner, 2014).

As one CIO is cited "we stopped thinking of the IT as a bad, and started thinking of it as what keeps the business running." And this is the pivot point for the modern organizations how to plan and manage IT stratigically – by closing the loop with the *Exploit* activities in the "value creation cycle" the companies would maximaze the gain from reusing ingredients, will steady advancing performance and profitable growth, at the same time chasing new business opportunities – see Figure 2.

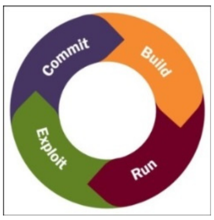


Figure 2: The IT Value Creation Cycle (Ross, Beath and Quaadgras, 2011).

# 3 INSIGHTS ON ALIGNED IT CAPABILITIES TO BUSINESS STRATEGY

For the benefit of any company it is most important to define and establish the IT architecture underneath the organization's business strategy. A well-formulated IT architecture typically consists of *content* and *processes* and describes the following key components of the enterprise IT architecture:

- Technology planning and management: strategy, governance and operations aligned to business processes
- Information and data flow architecture
- Applications architecture and functional systems, including correlated interfaces
- IT infrastructure: existing platforms, services, and adopted standards.

The "IT/Business Alignment Cycle" is a frequently used methodology which introduces a set of well-planned process improvement programs that systematically address a broad range of activities to permeate the entire IT organization and its culture. The four phases of the alignment cycle are (Nugent, 2004):

- The *Plan* phase translates business objectives into measurable IT services and helps close the gap between what business needs and expects and what IT delivers;
- The *Model* phase designs infrastructure to optimize business value and involves mapping IT assets, process, and resources , then prioritizing and planning to support business critical services;
- The *Manage* phase drives results through consolidated service support and enables the IT to deliver promised levels of service based on pre-defined business priorities;
- The *Measure* phase verifies IT commitments and improves its cross-organization visibility into operations.

Following the above IT/Business alignment cycle fosters organization-wide shared IT expectations and defines a common framework for a broad range of activities forcing alignment of IT and business objectives. This simple framework should be revisited periodically when there is a significant course correction in corporate directions or in the key components of the IT architecture.

In the evolving IT/Business alignment process several significant points should be considered.

*The first finding* reflects ***the lead on driving value from IT*** and the following critical steps should be executed:

- Set the directions for the IT-Business alignment process – define the company operating model, identify the key components of the IT architecture, articulate the strategic vision that the OM and IT is intended to realize;
- Lead the IT-business transformations – straight the activities to build the DP, complete the organizational changes needed to execute the vision;
- Preserve technology, data, and process standards – supervise the technology implementations conforming to the operating model, the platform enabling it, and adopted standards;
- Exploit the value – gain the advantage of the business agility provided by the adopted IT platform, reuse and innovate constantly to achieve sustaining technology S-curve.

*The second finding* reinforces ***Structure rationalization*** to transform IT from a costs center to strategic assets with business intelligence capabilities. The Gartner analysis on Future Directions of the IT industry from 2011, exemplifies where the transformations are the most appropriate – from lessening the *After the Sale* IT spending to substantial increase the investments in *Before the Sale* and in *The Sale* sectors – see Figure 3 (McGee, 2011). The process requires significant alternations in the enterprise requirements to support transformational initiatives such as: content-aware computing, social and semantic computing, information-enabled pattern-based strategy.


Figure 3: The IT Money Spending Model (McGee, 2011).

Only few years later, the current Gartner analysis shows a new Nexus of Forces – BI/analytics (social and information), cloud and mobile- as leading CIOs investment priorities forcing transformations in the traditional IT money spending model targeting *Before the Sales* and *the Sales* sectors– see Figure 4 (Gartner, 2015).

Based on the CIOs strategies reported in the table, IT and business leaders transform profoundly the role of IT from a strategic liability to strategic asset strengthening the customer experience and pursuing new channels of growth.

| Rank | Investment priority | 2014 | 2015 |
|---|---|---|---|
| 1 | BI/analytics | 41% | 50% |
| 2 | Infrastructure and data center | 31% | 37% |
| 3 | Cloud | 27% | 32% |
| 4 | ERP | 26% | 34% |
| 5 | Mobile | 24% | 36% |
| 6 | Digitalization/digital marketing | 17% | 11% |
| 7 | Security | 13% | 11% |
| 8 | Networking, voice and data comms | 12% | 12% |
| 9 | Customer relationship/experience | 11% | 8% |
| 10 | Industry-specific applications | 9% | 10% |
| 11 | Legacy modernization | 7% | 7% |
| 12 | Enterprise applications | 6% | 2% |

Figure 4: The CIOs priorities 2014/2015 (Gartner, 2015).

*The third finding* suggests modifying the Latin philosophy "Ex Chaos Facultas" ("From Chaos comes Opportunity") to "From ***Consumerization*** comes Opportunity" to reflect the current technology trends. Recent tendencies in IT utilization show that new technologies emerge first in the consumer market and then, after mass acceptance, are employed largely by business organizations. The expected consequence of this pattern is that across the globe companies are experiencing the most disruptive new technology trend of this decade: Consumerization.

Enterprises are capitalizing on the consumerization of IT and proliferation of mobile devises by developing applications aimed at improving employee productivity and customer satisfaction – see Figure 5. (Columbus, 2014).

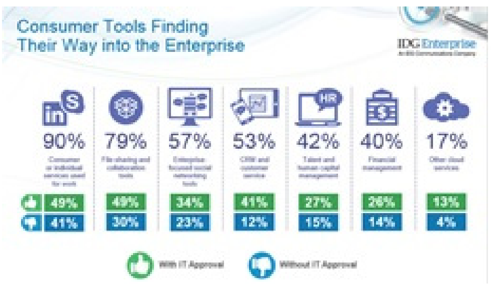


Figure 5: Consumer Tools into enterprise (Columbus, 2014).

Consumerization of IT, along with workforce mobility, and flexible, reliable, accessible and affordable remote computing, change forcefully the corporate IT lanscape affecting the relationship between enterprise IT, corporate users, and consumers. For organizational IT management, consumerization exemplifies the convergence of a demanding set of challenges such as information and infrastructure security, technology policy, data protection, and end-user technology. A new tendency -BYOD (Bring Your Own Device) and COPE (Company-owned, Employee-enabled)-driven mostly by current Consumerization of IT in the enterprise, is forcing companies to redesign or create their policy and rules on how smart portable devices can be used for both corporate and private purposes, and how the related expenditures should be covered.

For corporate management, consumerization of IT signifies a new strategy which supports business models and process innovations, talent strategy and customers' satisfaction, as well as corporate brand and identity. Consumerization of IT blurs the line between personal and work life, especially for mobile workers. Mobile workers make up about 39% of the employees in North America, 25% in Europe, and 42% in Asia, according to Forrester's analysis (Forrester Consulting, 2013). Their cohort benefits the business immensely by increasing productivity, and advancing collaboration and business agility, thereby improving customer satisfaction and climbing the rate of talent retention. Consumerized employees spread the boundaries of the workday and workplace, and it is fair to name them "anytime, anywhere workers."

*The fourth finding* is that in a digital economy every organization is challenged by IT constant innovations, and it should take a look again on the pivotal question: "What comes first: IT architecture or Business strategy?" The IT rapid advancement is spawning completely new industries in several different ways:

- IT makes new businesses *technologically* feasible – advances in nano-technologies made today's mobile industry possible. If we think about Apple's i-products – they came as of technological advancements and miniaturization, however Apple did something unique and far more smarter making not only a great technological product, but wrapped it in a superb business model. The Apple's true innovation was to enter and gain a substantial slice of the personalized entertainment industry – utilizing the technology innovations and make it easy, customers' friendly and demanding the control of all i-products and services.
- IT can spawn new businesses by creating demand on new products such as customized

financial services (mortgage, brokerage, and investment) there were not optional nor needed before the spread of IT caused a demand for them. Web 2.0 technologies help social networking and Big Data to flourish as multibillion dollar business, the new coming Web 3.0 with the next digital inspiration: semantic technologies, Internet of Things, M2M would make even beyond the current experience.

- IT creates new businesses within old ones. Many companies take advantage of excess capacity and skill of its advanced IT value chain and provide products and services to others based on them.

# 4 CONCLUSIONS

There are many other considerations and challenging implications in the IT-Business alignment process: asymmetric competition, speed of innovations, speed to the market, speed of organizational model's evolution. All these specifics require yet more efforts and analyses on how to integrate technology into the strategic business objectives and to excel on IT-enabled capabilities. The suggested simplified EA framework and findings for consideration have to provide a consistent, predictable, and agile experience when mapping and executing IT/Business alignment.

Further work is planned in two directions: how consumerization of IT adoption to the dynamic business objectives and current operating models can be evaluated and measured, and how Web 3.0 technologies would impact the business of IT at the enterprise level.

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# The Process of Process Management
## *Mastering the New Normal in a Digital World*

Mathias Kirchmer
*BPM-D, 475 Timberline Trail, West Chester, PA 19382, USA*
*University of Pennsylvania, Organizational Dynamics, Philadelphia, USA*
*mathias.kirchmer@bpm-d.com*

Keywords: Agility, ARIS, BPM, BPM-Discipline, Business Process Management, Compliance, Digitalization, Execution, Information Model, Innovation, Management Discipline, Process Model, Reference Model, Standardization, Strategy, Value-driven BPM.

Abstract: Today business strategies and operations are driven by scores of ever-shifting factors: from demographic changes, capital availability and legal regulations to technological innovations and an all present digitalization. Static business models are no longer able to keep pace with such dynamic change. Companies need a management approach that fits to this environment. Organizations need to master the "new normal" and deal proactively with our "digital world". In effect, they must know how and when to modify or enhance their business processes, which processes are optimal candidates for intervention, and how to move rapidly from strategy to execution. That's where the Business Process Management-Discipline (BPM-Discipline) helps. It enables organizations to deal with change successfully and create immediate as well as lasting competitive advantage. It delivers significant business value by converting strategy into people and IT based execution at pace with certainty. The BPM-Discipline creates a "strategy execution network". The BPM-Discipline is implemented through the "process of process management". Organizations look for a way to systematically establish their process of process management efficiently and effectively. This can be achieved using a holistic framework and reference model for the process of process management. The paper introduces the BPM-Discipline and how it is implemented through the process of process management, leveraging a powerful reference architecture in form of comprehensive information models as well as related tools and templates.

# 1 INTRODUCTION

In today's business environment organizations' strategies and operations are driven by scores of ever-shifting factors: from demographic changes, capital availability, legal regulations and customers who require something new every day to technological innovations and an all present digitalization. Static business models are no longer able to keep pace with such dynamic change. Companies need a management approach that makes them successful in this volatile environment. Organizations need to master the "new normal" and deal proactively with the opportunities and threats of our "digital world" (Sinur, Odell, Fingar, 2013). Companies need to become "Exponential Organizations" who achieve a significant higher output than peers through the use of new organizational techniques and related technologies available in a digital environment (Ismail, Malone, van Geek, 2014). In effect, organizations need to know how and when to modify or enhance their business processes, which processes are optimal candidates for intervention, and how to move rapidly from idea to action.

That's where the Business Process Management-Discipline (BPM-Discipline) helps. It enables organizations to deal with change successfully, drive their growth agenda and create immediate as well as lasting competitive advantage. Companies increasingly invest in areas of "intangibles" such as "business process" (Mitchel, Ray, van Ark, 2015). The BPM-Discipline delivers significant business value by converting strategy into people and IT based execution at pace with certainty to meet the requirement of the "new normal" and benefit from the opportunities of digitalization (Kirchmer, Franz, 2014) (Rummler, Ramias, Rummler, 2010).

Existing approaches to BPM focus in general on one or very few aspects of process management, e.g. implementing a process automation engine or setting up an enterprise architecture. There is a need for a comprehensive overarching approach to identify and establish all process management components required to form a simple but successful BPM-Discipline in the context of a specific organization. This is the topic of the research presented in this paper.

The BPM-Discipline is implemented through the "process of process management", just as other management disciplines are implemented through appropriate business processes: human resources (HR) through HR processes, finance through finance processes, to mention a couple of examples. The process of process management (PoPM) operationalizes the concept of the BPM-Discipline. It applies the principles of BPM to itself.

This paper defines the BPM-Discipline and its value. It explains how this management discipline is further operationalized through the Process of Process Management (PoPM). Then it gives an overview over a reference model for the PoPM, developed to enable a systematic application of the PoPM approach to build and run a value-driven BPM-Discipline. Finally the paper will share first experiences with the practical application of the PoPM.

## 2 VALUE AND DEFINITION OF THE BPM-DISCIPLINE

Research involving over 90 organizations around the world of different sizes and in different industries has shown that companies who use BPM on an ongoing basis get significant value in return (Kirchmer, Lehmann, Rosemann, zur Muehlen, Laengle, 2013) (Franz, Kirchmer, Rosemann, 2011). Basically all surveyed organizations state that the transparency BPM brings is a key effect. This transparency is on one hand a value by itself: It enables fast and well informed decisions which is in the volatile business environment we are living in crucial for the success of a company. On the other hand BPM and the transparency it provides also help to achieve other key values and enable the management of the trade-offs between those values. BPM enables four key "value-pairs":

- Quality and Efficiency
- Agility and Standardization (Compliance)
- External Networks and Internal Alignment
- Innovation and Conservation.

Let's look at an example. A company wants to improve its call centre process. Only few sub-processes are really relevant for clients and their willingness to pay a service fee for them. Hence you improve those sub-processes under quality aspects. Other sub-processes are more administrative. Clients don't really care about them. Hence, you improve those processes under efficiency (mainly cost or time) aspects, using appropriate BPM approaches. BPM delivers the transparency to achieve both values and end up with the highest quality where it matters and the best efficiency where this counts most. Or BPM helps to identify where it is really worth thinking of process innovation and where you can conserve existing good practices. Since an organization only competes with 15-20% of its processes it is key to identify where innovation pays off. This is again possible though the transparency BPM delivers. The values BPM delivers are shown in figure 1 (Kirchmer, Franz, 2013).

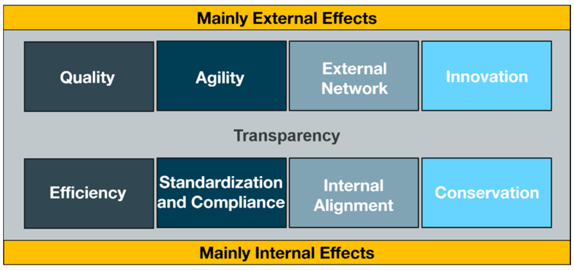


Figure 1: Values delivered by BPM.

In general all those values are important for an organization. However, depending on the overall business strategy, companies focus on a subset of those values. These values and the underlying strategic objectives need to be realized across organizational boundaries within a company and beyond, while focusing on creating best results for clients.

In order to achieve those values consistently it is required to establish BPM with its infrastructure as an ongoing approach to run an organization (Alkharashi, Jesus, Macieira, Tregear, 2015) (von Rosing, Hove, von Scheel, Morrison, 2015). BPM becomes a management discipline.

We define BPM as the management discipline that transfers strategy into execution – at pace with certainty (Franz, Kirchmer, 2012). Hence, we refer to BPM as the BPM-Discipline (BPM-D). This definition shows that BPM uses the “business process” concept as vehicle for a cross-organizational strategy execution, including the collaboration with market partners like customers, agents, or suppliers. The execution of the strategy can be people or technology based – or a combination of both. This definition is consistent with newest findings in BPM related research (Swenson, von Rosing, 2015). But it stresses the value that processes management produces and its key role as strategy execution engine.

The BPM-Discipline addresses the entire business process lifecycle, from design, implementation through the execution and control of a process. Hence, it handles the build-time as well as the run-time phase of a business process. The definition of BPM as a management discipline is shown in figure 2. We refer to it as the BPM-D™ Framework.

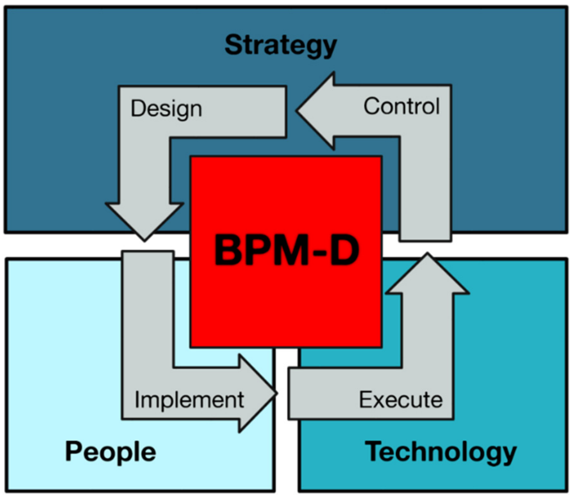


Figure 2: The BPM-D™ Framework: Definition of BPM as Management Discipline to Execute Strategy.

## 3 THE PROCESSES OF PROCESS MANAGEMENT TO IMPLEMENT THE BPM-DISCIPLINE

While over years many practitioners, especially executives, questioned the value of BPM, this situation has changed significantly in the past 5-7 years. Most organizations and their leadership start at least understanding the value proposition and the broader dimension of BPM. The challenge has become how to establish it in an organization in a pragmatic but systematic way with minimal up-front investment.

In order to resolve this issue we can look at other management disciplines and how they are implemented. An example is the discipline of Human resources (HR), as mentioned before. How do you implement the HR discipline? You introduce it into an organization through the appropriate HR processes, like the hiring process, performance evaluation or promotion process.

Consequently, you can implement a BPM-Discipline through the “process of process management”, the BPM process. You address the BPM-Discipline just like any other management discipline. If you interpret the BPM-Discipline as process itself, you can apply all the process management approaches, methods and tools to it – enabling an efficient and effective approach. You basically implement BPM using BPM.

In order to identify and address all key aspects of the process of process management we use the ARIS Architecture (Scheer, 1998), a widely accepted and proven framework to engineer processes from different points of view. This enables the operationalization of the framework so that it can be applied to specific organizations. Based on ARIS, the BPM-D Framework is decomposed into sub-frameworks. Result are four core frameworks describing the process of process management:

- BPM-D Value Framework
- BPM-D Organization Framework
- BPM-D Data Framework
- BPM-D Process Framework

The decomposition of the overall process of process management as shown in figure 2 into sub-frameworks based on ARIS is visualized in figure 3. The BPM-D Process Framework covers both, a functional decomposition and aspects of the control view of ARIS.

The BPM-D Value Framework is shown in figure 1 and has been discussed before. It describes the key deliverables (values) the process of process management (PoPM) produces. The use of this framework enables a consequently value-driven approach to BPM. This is especially important when you establish BPM as a management discipline so that you don’t end up just with another overhead unit but an organization that drives systematically value by executing strategy.

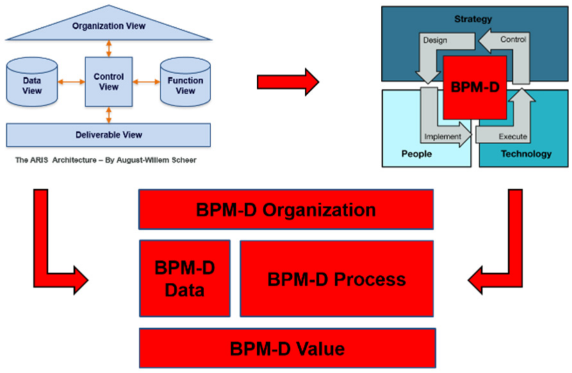


Figure 3: Operationalizing the Process of Process Management using the ARIS Architecture by A.-W. Scheer.

The earlier mentioned research studies also shows that organizations who apply BPM successfully have multiple different process specific roles in place. We identified over 40. The segmentation of those roles led to the BPM-D Organization Framework.

There exist two big groups of process-related roles: Core roles and extended roles. People with BPM core roles are part of the core BPM organizational unit, for example a centre of excellence (Alkharashi, Jesus, Macieira, Tregear, 2015) (Franz, Kirchmer, 2012). People with roles in the extended BPM organization are part of other organizational units. BPM roles can be centralized to achieve best synergies or decentralized to be close to operational improvement initiatives. Roles can be permanent or project based, relevant only for a specific initiative. In most of the cases the roles are internal roles. However, there is in more and more organizations a tendency to procure more administrative roles, like helpdesk activities or the maintenance and conversion of process models, externally, as a managed service. The BPM-D Organization Framework is shown in figure 4.

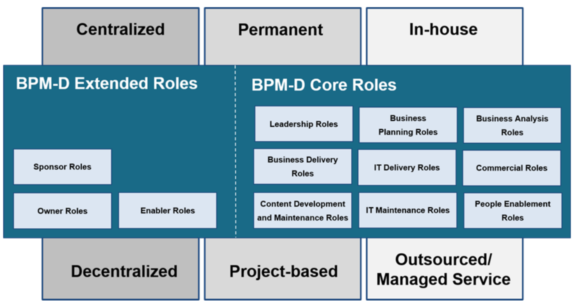


Figure 4: BPM-D Organization Framework.

Very important is an emergent top leadership role in the BPM-D core organization: the Chief Process Officer (Kirchmer, Franz, von Rosing, 2015) (Kirchmer, Franz, 2014a). This business leader owns the overall process of process management, hence leads the overall BPM-Discipline. The empirical research confirmed the trend of such an emerging top management position. Successful BPM organizations report in many cases directly to the board of a company.

The most important role in the extended BPM organization is the process owner, responsible for the end-to-end management of a business process. This role has to make sure things get done with the expected impact on the strategic value-drivers, using the BPM core organization as internal service group. Other groups of core and enabling roles are shown in figure 4.

In most of the organizations you don't have representatives for all the groups of roles right away or only part time roles. It depends on your overall BPM agenda which roles you need when. The required roles change over time, driven by the specific value the BPM discipline has to provide to execute on an organizations strategy. It is important to have both, core and extended roles in place to be on one hand able to execute, on the other had avoid to re-invent the wheel for every new initiative.

Next "ARIS view" to be addressed is the data view. The information used in or produced by the process of process management is summarized in the BPM-D Data Framework. That view helps to plan information requirements for the process of process management. This includes business strategy related information to enable the link between strategy and execution. Example are strategic goals or value-drivers. But also operational information, like project related information, enterprise architecture, organization or tool and technology related information. The BPM-D Data Framework is shown in figure 5 in form of a simplified entity-relationship model.

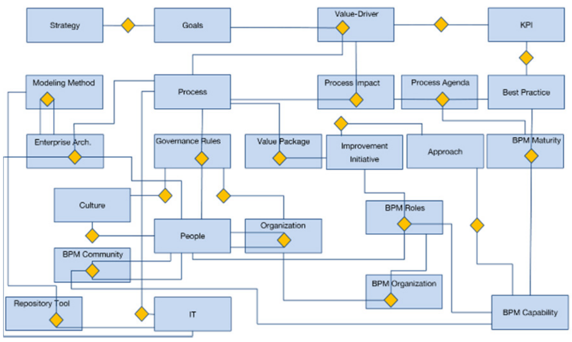


Figure 5: BPM-D Data Framework.

Most important for the operationalization of the process of process management is the BPM-D

Process Framework, covering the function and control view of the ARIS Architecture. It represents basically the first three hierarchy levels of a functional decomposition and a content related segmentation of the key activities of the PoPM.

The structure of the Process Framework is based on the principle thinking suggested in Scheer's Y-Model to segment the processes of an industrial enterprise (Scheer, 1995). In order to make the PoPM happen an organization requires project-related sub-processes (activities), focussing on improving specific business processes. On the other had it also needs to have "assets-related processes" in place to execute improvement projects efficiently and effectively. Both, project and asset related sub-processes require planning and execution. This results in four groups of BPM-related sub-processes as shown in figure 6.

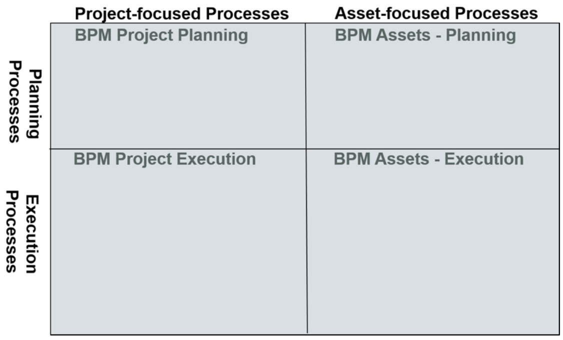


Figure 6: Segmentation of BPM-related activities.

The specific sub-processes of the PoPM were identified based on the analysis of over 200 process management initiatives. The result is shown in the BPM-D Process Framework in figure 7.

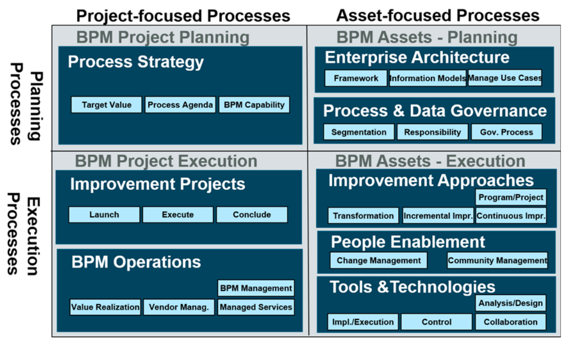


Figure 7: BPM-D Process Framework.

The BPM Strategy identifies high impact low maturity processes, BPM capability gaps that need to be filled to improve those processes and the development of a BPM Agenda, showing which processes are improved when to achieve specific business objectives and which BPM capability gaps are closed during that specific improvement initiative. Hence, every initiative delivers immediate business value while creating lasting process management capabilities. Improvement projects follow a straight forward project approach: launch, execution, and conclusion of the project. BPM-Operations enable the execution of activities outside specific projects, for example the value realisation once a project is already concluded.

The Enterprise Architecture related sub-processes handle all activities necessary to create and manage information models, necessary to improve specific processes or keep them on track. Process and Data Governance sub-processes organize the way process management is executed, hence, grant the power to take decisions, drive action and deal with the consequences of those actions. Important here is the integration of process and data governance (Packowski, Gall, Baumeister, 2014). Insufficient master data quality leads in many cases also to ineffective processes. An integrated governance approach aligns both aspects.

The availability of improvement approaches and of people trained in those approaches enables improvement projects which use those capabilities. People enablement is all about information, communication and training. Hence it prepares people to think and work in a process context and deal with process change successfully. Tools and Technology related sub-processes handle the technical infrastructure required for a successful BPM-Discipline, including for example automation engines, rules engines, repository and modelling tools, process mining, strategy execution tools, social media, the internet of things and other internet-based approaches, or e-learning applications. These are core BPM tools but also additional technology required to increase the performance of a process to the required level.

While all the sub-processes of the PoPM shown in figure 7 can be important in a specific company context, organizations only rarely need all of them in full maturity. The specific objectives of a company's BPM-Discipline determine the importance of a specific sub-process and the required maturity level. Once the relevant sub-processes of the PoPM are selected and their required maturity level is defined, the necessary roles and information are identified using the appropriate BPM-D frameworks. All frameworks need to be configured consistently to a specific organization, its strategy and business context. The right application of the BPM-Framework and its sub-components enables companies to focus on what really matters, improve those areas efficiently and effectively as well as to sustain those improvements. These key tasks of a BPM-Discipline are visualized in figure 8.

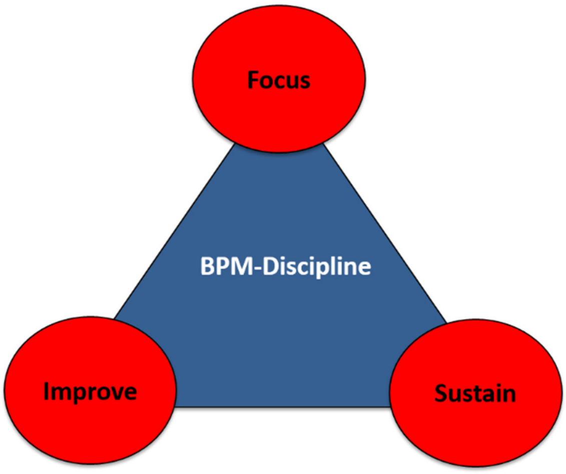


Figure 8: Key Tasks of a BPM-Discipline.

The BPM-D Framework with all its components is patent-pending. It is a strategy execution environment helping organizations dealing successfully with the challenges of the new normal in a digital world.

## 4 REFERENCE MODEL FOR THE PROCESS OF PROCESS MANAGEMENT

In order to operationalize the BPM-D Framework and its components further, the framework is transferred into a more formalized reference model. Reference models are generalized knowledge, structured and documented in a manner that enables adaptability to specific situations (Kirchmer, 2011) (Fettke, Loos, 2007).

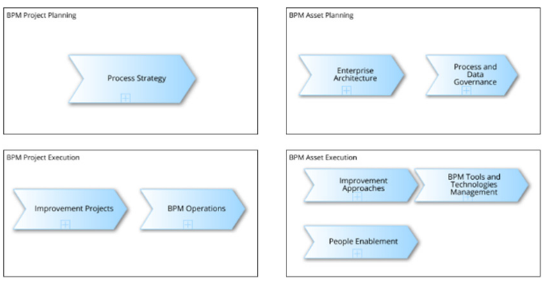


Figure 9: Level 1 of BPM-D Process Reference Model.

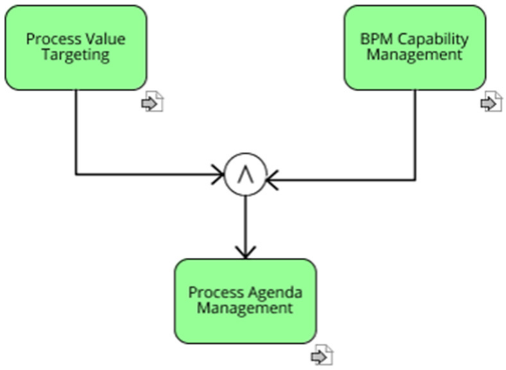


Figure 10: Level 2 of BPM-D Process Reference Model – Process Strategy.

During the development of the BPM-D Reference Model the BPM-D Process Framework is further detailed and integrated with the other BPM-D sub-frameworks. The control flow logic is added to the functional decomposition. Key functions are linked to tools, templates or other job-aids supporting their execution.

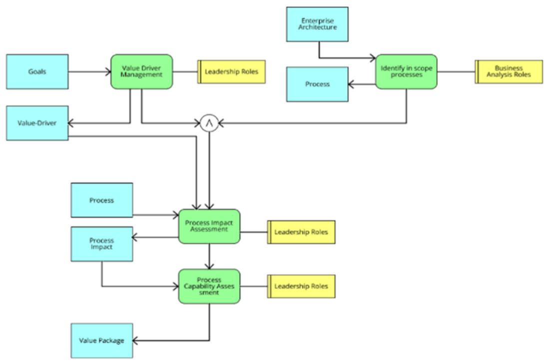


Figure 11: Level 3 of BPM-D Process Reference Model – Targeting Value of the Process Strategy.

The process framework is described on 3 levels of detail. The top level is represented as value chain diagram (VCD), level 2 and 3 as event-driven process chain (EPC). The EPC notation was selected since it is focusing on the description of the business content and has less formal requirements than other methods like the business process modelling notation (BPMN). It is in general easily understood by business practitioners. Also people used to work with other modelling methods can usually quickly adjust and understand the EPC notation. In order to support a potential automation of some of the sub-processes of the process of process management, level 3 processes are also available in BPMN (simple model conversion). These BPMN models can be used as starting point for the specification of application software supporting the PoPM. While this redundancy needs to be managed we feel that at the current point of time it helps to achieve both, easy use of the content by process practitioners and by software developers.

Figure 9 shows level 1 of the process reference model. Examples for levels 2 and 3 are represented in figures 10 and 11. On level 3 process models, for example in the model shown in figure 11, it is exactly described which BPM roles are required, what the people in those roles have to do, which data (information) they use and in which logical sequence they work. Hence, the process is sufficiently described to be implemented (Kirchmer, 2011).

The reference model is developed in a web-based process repository tool. This enables the easy access from all relevant locations and reduces tool maintenance to a minimum. It can be easily transferred into all market leading modelling and repository applications. The reference model currently consists of 67 individual information models.

The implementation and execution of the level 3 processes is further supported through the link of the models to execution tools, templates and other job aids. The sub-process "BPM Capability" of "Process Strategy" is, for example, linked to a BPM maturity assessment tool, based on the BPM-D Framework. The "Responsibility" sub-process of the "Process and Data Governance" is linked to job aids supporting the establishment of a BPM Center of Excellent with its different roles and the introduction of process and data governance to a specific end-to-end process. The reference model includes over 20 tools, templates and other job-aids.

# 5 FIRST EXPERIENCES

The BPM-D Framework and Reference Model or components of it have been applied in 23 organizations of different industries and sizes over the last two years to implement or apply the process of process management. This has been done through a combination of consulting, coaching and educational activities, combined with appropriate research activities to continuously improve the process of process management reference model.

Let's look at a couple of examples: The CEO of a medium-size consumer goods company has focused for several years successfully on a small niche market. The company offers their products at a high price enabling high revenues and profits – in spite of a relatively high cost level. Now competitors entered that niche market and offer similar products at a much lower price. The CEO decided to adjust strategy, reduce their prices in the current market and enter new market segments with new products. However, to reduce prices they need to reduce cost. None of the functional executives sees significant cost reduction potential in their own areas. They blame other departments for the cost issues. Also the innovation related processes are not performing at the level required. A process repository with its process models did not really help: the models are outdated and inconsistent regarding semantic content as well as modelling format. The only person who is somehow familiar with the models and the repository has left the organization. There is no cross-functional management in place with responsibilities beyond department boundaries. It is very difficult or even impossible to identify focus areas for cost reduction or a consistent approach for the development and launch of new products.

The situation is addressed through a combination of defining and establishing an appropriate BPM-Discipline through the according process of process management, combined with the immediate application of the new capabilities to "no regret" processes. Additional improvement targets are defined when all high impact low maturity processes are identified by the new BPM-Discipline. Key areas of the PoPM addressed in this initial BPM-Discipline launch are the development of a process strategy, introduction of a simple process and enterprise architecture approach, definition of a basic process governance, outline of a straight forward model-based improvement approach and some targeted training.

Another typical example is a large financial organization. They have invested over the last four years significant money into what they call "BPM". However, none of the top executives has seen any business impacts or usable results after all that time and money spent. A stakeholder assessment and BPM maturity analysis showed that almost all BPM related initiatives focus on tools and technologies – for all business units in parallel. There is, for example, a process repository in place with over 2000 models – how to get value out of them is unclear. A flexible process automation is in the works – but business changes faster than the technology can be adjusted. And it is impossible to focus on just one area because business priorities are not or not well enough defined.

The introduction of a value-driven BPM-Discipline, led by a top manager as Chief Process Officer" and its use for a simplification of processes with known issues as preparation for a more focused and business-driven automation is used here to address the current issues. Key areas of the PoPM addressed are the value-driven process strategy with its prioritization approach, process and data governance, a process model based simplification and standardization approach and several people enablement initiatives. Existing capabilities are linked to specific outcomes to achieve step by step a value-driven approach to BPM.

The experience with the first 23 organizations shows that organizations looking for the systematic implementation of a BPM-Discipline through the process of process management fall into three groups:

1. Organizations have launched one or even multiple process improvement initiatives but the results are not sustained. Every new improvement initiative starts from scratch, not using existing knowledge about business processes systematically.
2. Organizations put in place many components of a BPM infrastructure (e.g. process execution environments) but have not achieved real business value through their BPM activities.
3. Organizations launched some improvement initiatives and built some BPM infrastructure but both do not really fit together, it is unclear what the next steps and priorities are. The produced business value is limited.

Organizations of the first group establish the “project-focused” sub-processes of the PoPM but forget about the activities and infrastructure necessary to keep the improved processes on track and to be able to create synergies between different initiatives over time. In those cases “asset-focused” sub-processes need to be addressed. In most of the cases this results in a combination of governance, enterprise architecture and people enablement processes, combined with the development of an appropriate value-driven BPM agenda.

The second group of organizations gets lost in all the available methods, tools and technologies but forgets to identify how to create business value through them. The link of BPM activities to strategic value-drivers and the launch of initiatives effecting those value-drivers is key here. Hence, the “project-focused” sub-processes of the PoPM need to be addressed. The launch of a process strategy initiative is here most important: identifying high impact low maturity processes, the required BPM capability and based on those the development of the BPM agenda. This needs to be combined with the launch and execution of improvement projects and the consequent value-realization. BPM capabilities can be adjusted according to the requirements identified in the BPM agenda.

Most organizations belong to group three. They have some BPM capabilities and improvement initiatives in place but the BPM journey is missing direction, focus and clear business impact. They don’t have a BPM-Discipline in place but know how to apply a number of methods and tools, e.g. Six Sigma. Instead of strategy execution, BPM activities result in operational fixing of symptoms. Here a combination of a real outcome-focused process strategy, the management of the process knowledge in an enterprise architecture and a well defined (but simple) governance approach are good starting points to move towards a value-driven BPM-Discipline.

Here some key lessons learned from first practice experiences:

- Get top management support. Establishing a value-driven BPM-Discipline requires the top-down support, best for the entire company, but at least for the business unit in scope.
- Identify business processes where you can deliver immediate benefits while building the required lasting BPM capabilities. Otherwise sponsors will lose patience.
- Set clear priorities, don’t try to “boil the ocean”. Organizations who launch too many initiatives at once often fail.
- Keep things simple, “less is often more”. This is especially true for the use of tools and technologies.
- Encourage innovation and creativity instead of punishing people for making mistakes.
- A value-driven BPM Discipline is an enabler of growth and strategic agility, not just a cost reduction engine.
- People are key for success. You need to treat them accordingly.
- A value-driven BPM-Discipline and its leadership recognizes the business value potential of technology and digitalization and makes it transparent to the organization. It enables real business value from digital initiatives.

The first experiences with the BPM-D Framework and the reference model of the process of process management have demonstrated the business impact of the approach and enabled the continues improvement of the reference model. The reference model allows to identify and establish the appropriate BPM capabilities in the company-specific context quickly and at low cost while applying them immediately to achieve fast business benefits.

A company can use the adjusted reference model as basis for the definition of the company-specific BPM processes. The process of process management is transferred into an operational business process. It becomes part of the enterprise architecture of the company. The owner of the process of process management, a "Chief Process Officer", manages this process.

## 6 CONCLUSION

Business Process Management (BPM) has become a value-driven management discipline that transfers strategy into people and technology based execution – at pace with certainty. This management discipline is implemented through the process of process management. It enables an organization to master the new normal in a digital world.

The BPM-D Framework with its sub-components and the reference model for the process of process management help organizations to establish a value-driven BPM-Discipline efficiently and effectively. The reference model and the tools behind it are continuously improved based on practice experience as well as newest academic thinking.

While BPM-D frameworks and reference model have already reached a good maturity level, there are still improvement potentials left. Here are several areas we focus our on-going research on: The reference model in the current level of detail needs to be continuously updated to include new thinking and even better practices. Areas where this is especially important are the integration between process and data governance, people enablement using appropriate tools and technologies, e.g. social media based approaches ("Social BPM") and the consequent link to value of the various enterprise architecture, tool and technology components.

In some areas of the reference model the addition of level 4 processes (one level of detail more) can be helpful. This is the case in areas that are less company and implementation specific, e.g. around the process strategy.

Most powerful for the practical application has been the addition of execution tools and templates related to the PoPM reference model, e.g. the development of the process prioritization tool, the capability assessment tool, the weak point analysis for rapid process simplification and improvement or the process governance and BPM Center of Excellence job aids. More of such enablers can be added.

The PoPM reference model also lays the basis for the development of an application software system supporting the management of a value-driven BPM-Discipline. A design of such a system is developed, a related patent is pending. Innovative add-on components are continuously required.

The BPM-Discipline and the underlying process of process management enables companies to create an end-to-end "value network" around the existing organizational structure. This is the basis for performance and productivity in the new normal of our digital world. The BPM-Discipline becomes the strategy execution engine of an organization.

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# 30 Years of Consulting and Developing for Food Processing

Coen Suurmond
*RBK Group, Keulenstraat 18, 7418 ET Deventer, The Netherlands*
*csuurmond@rbk.nl*

Keywords: Business Processes, Business Practices, Information Systems.

Abstract: The paper gives an overview of the company I have been working at and the practical work I have been doing for some 30 years, as well as the impact of the practical work on my theoretical positions. The company is rather exceptional in its application of a broad scope of knowledge areas in a specialised market. At RBK we both design production facilities & technical installations, and develop and implement information systems for the food processing industry. Short descriptions illustrate some characteristics of our projects and systems, the problems we attacked and the solutions we found. The impact of the practical experiences on my theoretical insights is discussed in the last part.

## 1 INTRODUCTION

For the past thirty years I have been working at the RBK Group in Deventer in the development of information systems for the food industry. I have combined my work as a practitioner with research into the functioning of information systems in enterprises. In this paper I will give an overview of my experiences in practice through the years and what its influence has been on my theoretical insights. The always recurring confrontation with the physical reality of the shop floor and the wide range of perspectives (from process technology, technical processes, management sciences and information technology) have always provided a rich feeding ground to experience how people handle information in business processes. The cooperation with all kinds of departments at our customers (production, quality control, commerce, logistics and controlling) has also been an ongoing exercise in doing justice to various interpretations of ‘the same reality’, and an ongoing warning against reducing reality to a single perspective.

Below I will first provide a brief overview of the history of the company and the main characteristics of our customers and their products. This is followed by paragraphs exemplifying characteristics of our projects and systems over time. It will be concluded by an overview of how these projects and systems have contributed to a number of specific theoretical insights.

## 2 THE COMPANY AND ITS CUSTOMERS

### 2.1 Hans Kortenbach and RBK

The company RBK (“Raadgevend Bureau Kortenbach” = Kortenbach Consultancy) was founded in 1979 by Hans Kortenbach, a visionary and driven man. Kortenbach started out young as a refrigeration technician in the middle of the 1950s. About ten years later his employer tasked him with setting up a site in Emmeloord, which led to intensive contacts with fish processing companies in the pre-eminent and innovative fishing port of Urk. Here, Kortenbach gained management experience, both as director of the site and with the ways the customers conducted their business. In the second half of the 1970s this led to a management function in a meat processing company.

However, managing a production company is very different from the project-dominated environment of an installation company. Kortenbach decided in 1979 to set himself up as an independent consultant to apply his technical expertise, process knowledge and business knowledge to the fish and meat processing industries. The next year he hired an electro-technical engineer, because he saw opportunities in linking (semi-)electronic scales to computers (we are talking about a time in which Kraftwerk used a synthesizer and a soldering iron). The inventiveness and the results achieved by the new employee led to a long cooperation with the then pre-eminent supplier of scales in The Netherlands for the development of weighing/registration systems.

The 35-year history of RBK essentially shows the expansion of the knowledge areas mentioned above for food processing companies and for cold stores. Part of our company is about consultancy and design, part is about providing information systems for its business processes. Throughout these years we have wanted to contribute through our practice-oriented approach based on the integration of very different knowledge areas. We are specialised in terms of our market, but we are very broadly oriented in terms of our disciplines. The [added] value of our approach is illustrated by our approach to building and construction. New development projects tend to start with the architect and the general design of the building. However, at RBK we start with the design of the primary processes and their required large technical facilities (of which the refrigeration system in terms of complexity, of investment and of weight is often the main one) and then our building engineers ‘construct a building around it’ (and our architects ensure that it will be a nice-looking and well-designed building).

## 2.2 IT Systems in the Early Years

From the first years our computers would be connected to the outside world with peripheral devices (especially: electronic weighing scales), with product detectors, and with transport systems. Besides regular parallel and serial interfaces we had to find solutions for dealing with digital inputs and outputs. That is why we started with the ITT3030 microcomputer with a 4MHz Z80A processor, 16KB internal memory, two 560KB floppy disks for ‘mass storage’ and transferring data; operating system CP/M and BASIC as programming language. The modular architecture of the ITT3030 provided a good basis for connecting peripheral devices. An example from this period was a weighing system that could be wireless controlled by the driver on a forklift (this was in 1983).

From 1985 we used the IBM compatible PCs with MsDos as operating system and Pascal as programming language. For digital inputs and outputs these computers were much less suitable than the ITT3030, but we created our own solution via relay boxes (controlled via the parallel port) and via creative use of the control lines of the serial interfaces. From 1989 the system landscape for our shop floor control systems consisted typically of a Novell file server, a number of PCs connected in a local area network, and an AS/400 based system for purchasing, ordering and invoicing software (in 1989 we incorporated a software company with AS/400 software).

For process control we have used single-board computers in combination with in-house developed PCBs for about ten years starting from 1983. The single-board computers where initially bought from a supplier until a creative genius designed and built a single-board computer for us in 1987. A compiler compatible with Borland Pascal was also developed for this single-board computer. This had the large advantage of being able to perform a large part of software development and testing in a regular PC environment. The last of these systems still run at our customers today. However, this development for this system was discontinued in the early 90’s in favour of the application of industrial standard equipment for process control (PLCs). Now we use a very small model PLC controlled over Ethernet for controlling small scale digital inputs and outputs connected to our shop floor systems.

In a nutshell: from the beginning we have always been dealing with the connections to the physical world. In early times we had to create our own arts-and-crafts solutions, and later on we moved to the application of industrial standards.

## 2.3 Our Customers

The customers of RBK are chiefly production companies of fresh and perishable meat and fish products and cold stores for logistic services. The variability of the raw materials is an important property, at the same time the customers ask for standardised finished product with consistent characteristics. Both on the supply side and on the distribution side the typical lead times are one or two days. Due to these characteristics and due to often volatile demand, production schedules are often revised.

It has always been demanded of suppliers of fresh food products to deliver daily for a sometimes strongly varying demand. The phenomenon backorder is not applicable; a shortage one day cannot be compensated for by an extra delivery on the next. At a number of our customers the full supply of raw materials is processed to end products and delivered to their customers within 36 hours after arrival (at a daily capacity of 600 tonnes of raw materials, against ‘just’ 200 tonnes 25 years ago).

In general our customers have a flat organisation with a small number of experienced practitioners in key positions. This is necessary because of the complexity of the processes, because of the short lead times and because of the uncertainties both in the supply of raw materials and in the demand for finished products. Through the years the organisations have become larger and more formal, with a larger intake of higher and more broadly educated people.

### 2.4 Registration on the Shop Floor

The basic principle for the registration system and the databases it feeds has always been that it must be possible to register what actually happened, regardless of planning or norms. Of course systems must warn in case of deviations, but if an authority indicates that it should still happen then it must be registered. This is also the only reliable basis for traceability, a theme that has become increasingly dominant over the last few years.

From the early years our systems have had a real-time nature in two different senses. Firstly, the systems provide a view into the progress and actual yields in the production at any time, the essential basis for monitoring and adjusting production. Secondly, our systems are partly synchronised with events in the production lines and transport systems. ‘Real time’ in the first sense requires a typical cycle time of about one to five minutes, ‘real time’ in the second sense requires a typical cycle time of 0,2 – 1,5 sec. The interval between two consecutive registrations can be 5 seconds or less.

## 3 PROJECTS THROUGH THE YEARS

### 3.1 1980 – 1990: Realisation of the Vision of Hans Kortenbach

In the first decade of RBK’s existence there were two kinds of projects. Through the collaboration with a weighing scales supplier came orders for weighing registration systems for production companies, and later also for weighbridges. In short these were orders according to the specification of a customer, variations on a theme. The second stream of projects resulted from the innovative work of Kortenbach in the design of companies along with their technical installations. In Kortenbach’s vision large gains could be made by breaking through the traditional approach of fragmentary design per installation part. In the project of a factory for the production of dry sausages this approach was expressed in the design of the maturing and drying processes in climate chambers. Instead of a system with a closed air treatment unit for regulating temperature and humidity a system was used here that mixed in outside air, significantly reducing energy expenses. The control system is here tasked with regulating the intake of outside air based on the conditions in the climate chamber and the temperature and humidity of the outside air. Another aim of Kortenbach at the realisation of the new factory was the centralisation of all process installations (a number of cooking/smoking chambers, a number of climate chambers for maturing/drying, eight different process installations in total) to allow control and monitoring from a single point.

This vision was realised using a Compaq 286 PC (placed in a technical area) combined with a single-board computer for I/O processing (in-house developed) and a screen with a 4x4 keyboard in the (wet) production environment for control and monitoring of the processes. In our Borland development environment we made use of in-house developed multitasking on the application level: within a single application a number of different autonomous processes could be maintained in real-time (with a cycle time of at most 1 or 2 seconds). A conventional DOS-application waits for user input or it may be busy for an extended amount of time executing a procedure. In our DOS-applications the program never waits for anything, but is always cycling through a number of processes in an infinite loop which may or may not have events to be handled. A number of these applications are still in operation at our customers today, sometimes with more than 25 years of service.

A special challenge in this project was the user interface in the production area. How do you provide the user with insight into the current state of affairs in eight process installations (temperature, humidity, processing step, possible alerts) on a screen of 25 lines of 80 characters with a single glance and how do you organise the control of these installations on a keyboard of 4x4 keys? These limitations led to two views; one with an overview of all process installations with process parameters and the primary controls (starting/stopping a process, selection of process recipe in the foreground and a second view with the process data of the technical installations in the background. Everything was solved neatly in a controllable and clear system. I only realised the specialness of this approach years later when I visited another factory of sausages and I saw a tangled mess of local control panels and dial controls for all kinds of settings!

For the execution of the control system the customer was involved at only two points: before the start, when Hans Kortenbach had to persuade the customer of the value and feasibility of this approach, and nearly at the end to explain and check the control functions. Everything in between consisted of realising the views of Kortenbach based on: (1) the analysis of both the processes in the product itself (drying, maturing, cooking, smoking), (2) the analysis of the physical principles of climate control and of the relationships between pressure, temperature and humidity, (3) the analysis of the technical processes of the different components of the process installations, and (4) the mutual relationships between product, process installation and physical principles. For the development of the application with all process controls it was necessary to gain a lot of knowledge of the underlying principles (primarily based on the knowledge of Hans Kortenbach, supplemented by literature about the different subjects), and very little was written down (which was uncommon with automation projects within RBK at any rate).

## 3.2 1989 – 1995 Foundation for Shop Floor Control Systems

In early 1989 we realised our first weighing systems for shipping fresh meat. The first system with one weighing station in April, the second system with three independent weighing stations in a few months later, and the third system as a network solution at the end of that year. Each of these systems were connected via data transfer to a sales / invoicing system written in RPG on the IBM AS/400 platform. These systems were the start of a long and successful development with several offshoots. The variety of the offshoots eventually also led to major problems in the maintenance of the software, hurting both the customer (unexpected surprises with new versions) and for us as its supplier (more and more effort spent in maintenance, at the cost of new developments).

The first weighing systems for shipping were quickly followed by a variant system for the registration of production data and the calculation of deboning yields. This added an entirely new dimension to the package and to our expertise. Registration of shipping weights is relatively straightforward (registering the weights as basis for invoicing the customer), although the circumstances are rather special (time pressure, cold and wet environment, ensuring that everything is weighed exactly once). At the weighing for production the main process is also straightforward: weighing incoming and outgoing streams per production order, but there are a lot more dimensions than just the weights. Product coding and product recognition is an important issue, as well as quality control. An example is registering a product with some quality defect, no longer suitable for the continuation in the main process. For the evaluation of the production yields this product has to count as the main product that it should be, for the financial result it has to be valued at a reduced rate. Different stakeholders such as production management, external deboning crews (working at piece-rate), quality control, sales, and controllers may have very different views on the same products and the same calculations.

The development of this calculation system was accepted against a fixed-price (which was certainly not on the high side) but had eventually a turn-around time of over one year, due to all the additional aspects. The results of this system for the customer were good at first and eventually they became very good. The company was able to achieve significant improvements in process efficiency and product quality because the system gave detailed insight into the production results and into deviations from production norms. In this development I personally spend a lot of time near the production and with the production people, and I gained a lot of experience with the ins and outs of production itself, production registration and production accounting. The recurring themes in this process were: (1) how do the different departments of the production company look at the information and what do they do with it? (2) how do we achieve a reliable registration in such a production environment? (3) how can we explain the system to the weighers on the shop floor and to the users in the offices? In this project we had to learn the hard way how to deal with the physical production reality, the no-nonsense approach of dedicated production people and the multiformity of reality observed from different perspectives. As a ‘by-product’ we learned to act as a kind of intermediary between different stakeholders at our customers.

This lengthy project taught me something essential: the importance of a few people at key positions and the importance of an organisation that asks questions in the use of an information system. The physical position of the main user at the entrance of the production area was pivotal. He was in a position to have a good overview of the area with its various production lines, he could monitor the supply and availability of raw materials behind him, and he had an overview of the actual production yields in in real time on his screen and in case of deviations he could immediately enquire after them. On top of this he had the experience and knowledge to judge situations and he was an important information channel from production management to the shop floor. All of this was not based on some formal structure, but rather on a well-oiled organisation with a natural distribution of roles.

The large value of this was not immediately clear to me, but became clear years later when I saw how our system functioned a lot worse at other sites of the same company with identical production processes. This difference was mainly due to the quality of the local organisation, in which our system was just used as a machine to perform some specific task. When an information system is not used to evaluate situations and to ask questions, then it quickly degenerates to just an expense. On this second site office workers checked production yields once a week, while at the first site the yield of each and every production order was checked immediately upon completion of the order. The difference: a lot of money won or lost because of production yields.

## 3.3 2000 – 2010 Years of Renewal

During the period 1995-2010 the systems whose initial developments were described above were expanded upon, and a number of times they were drastically technically revised (e.g. the transition from DOS to Windows, a transition that will not be discussed further here).

For the process controls of refrigeration equipment there was an essential shift of emphasis from technical perfectionism towards orienting on the interests of all stakeholders. A quality inspector wants to see whether the temperatures remained within the agreed upon specifications, a general manager wants to see what his energy consumption has been, the technical service wants to quickly see what is going on in case of malfunctions, the same goes for the refrigeration technician, and our own consultants want to see how well the installation performs as a whole and where the settings may possibly be improved. This shift of focus at the same time reduced the complexity of our control systems and improved the performance for the stakeholders. An interesting instrument for the technical stakeholders is the so-called video recorder, which allows processes from the past to be viewed along with all logged process parameters and control actions. Because in case of trouble shooting ‘looking’ is often a much cheaper and a more efficient process than ‘thinking’, this is a highly valuable instrument for the technicians. This shift from complexity and perfectionism towards intelligibility and visibility of the behaviour of our control systems had much to do with internal personnel changes within RBK, where one of our refrigeration consultants was placed in charge of the software development for our process control systems.

For the weighing/registration systems there also was an essential change in how our systems were oriented (coinciding with the change from DOS to Windows). Traditionally our systems were based on production orders with input of raw materials or semi-finished products and output of (semi-)finished products. A conventional approach to stocks would mean that stocks are consumed on input to a process; and that stocks are created on output from a process. The disadvantage of the conventional approach, however, is that between input and output the goods are “absent”. Moreover, the modelling of some curing processes that last for days or weeks can be a burden. In these cases, the product is transformed (so it is an order) and the product is in storage (so it is a stock). As we are opposed to unwarranted reduction of reality, and we did not want to choose between production order and stock, we decided to have it both ways. Our new system was designed in such a way that everything can be considered as stock, all transactions are modelled as stock movements. Production orders are just a way of registration of inputs to a process stock and outputs from a process stock.

As a bonus, this approach also provided a neat foundation for another difficult issue: how to deal with the concept of “lot”. Lot management is an essential part of tracking and tracing. The problem, however, is that different stakeholders tend to have different ideas about what defines a lot. This is consistent with the OED definition of a “lot”: “A number of persons or things of the same kind, or associated in some way; a quantity or collection (of things); a party, set, or ‘crew’ (of persons); also, a quantity (of anything)”. This is a good definition and explains the multiformity of reality: different stakeholders will have different views on what qualifies as a lot. In our new system we dealt with this problem by using a system-defined concept of base-lot, and by having provisions for all kinds of external lot designations as extra references. Keep the internal world of your system consistent, and allow for multiformity of the external world(s)!

## 3.4 2010 – 2015 Architecture and Integration

Some years ago the need arose to modernise a third group of systems at our customers. We have had registration systems for individual products in a line process and control systems for internal transport of products for over 25 years at RBK. These systems had been the almost exclusive area of expertise of a single employee during this time. This held true both with regard to his process knowledge (what happens on the line?), to his mechanical-technical knowledge (how do the transport systems behave?), and also to his software and his IT toolbox for dealing with the real-time aspects, for handling the inputs and outputs, for data management, for visualisation, and for all kinds of communication with peripheral equipment and with other systems. Over the years, this employee has been assigned to different departments in our RBK organisation. In each department, however, the differences with its main activities were so great that in practice the development and support of these systems has effectively been a one-man department within RBK for 25 years.

As regards the contents of this kind of systems, an important issue is that across customers the same terms can have different meanings (homonyms), that the same thing can be referred to by different terms (synonyms), that this terminological ambiguity also regularly exists across departments within a single customer organisation. This phenomenon does not contribute to the entrance of newcomers to the field, and makes the transfer of knowledge difficult.

A further challenge in these kinds of systems is the coexistence of multiple methods to identify one individual product (tracking number from the supplier, tracking number from the process, RFID in the product carrier, RFID in the product itself), and that none of these methods is completely reliable in practice. The system has to be able to handle the various identifications concurrently and to use different identifications as a reference in the communication with other systems, also when identification may be missing or when some identification numbers are not unique. Incidentally, this problem of multiple and not fully reliable references is becoming an increasingly big problem in the external and internal supply chain. The supply chain seems increasingly to be a kind of dumping ground for uncoordinated identification systems of all kinds of partners in the chain.

We thus had a system issue to solve (a heterogeneous system landscape with our system containing elements of process control combined with elements from production systems, and to be integrated to several third party systems), a pre-existing issue to allow the employees of our various department to cooperate in a meaningful way, and, especially, to enlarge the group of people that could contribute to the development and maintenance of this kind of systems. Last but not least: RBK had to be able to apply the same standardised system to other customers with different configurations and terminology.

We found our solution for the system architecture and information architecture by an essential separation between the following system components: (1) a component for tracking the product during transport (‘tracking system’), (2) a component for recording data of the individual product (‘data system’), (3) a component to relate the physical and data system (‘synchronisation system’), and (4) configurable control terminals for registrations in the production line. The tracking system is the first to detect the individual product, assigns to it a unique system token, and tracks this token throughout all transport movements. The terminals of the data system are configured to record certain characteristics with the individual product at their position on the line. The synchronisation system ensures that the characteristics are recorded with the correct individual and that actions on the individual are triggered at the right time. The work stations are configurable thin clients in the production line with a number of buttons on the touchscreen to record characteristics and a mechanism to show the movement of the product during registration. The work stations are connected to the synchronisation system. The individual system components would be developed by different software groups (the tracking system by process control group, and the data components and user interfaces by the shop floor group, and the synchronisation system with its messaging as a joint effort).

With this set-up we can fully meet the system requirements. Through the use of a unique system-generated token for identification we have disconnected ourselves from the dependence on existing external identifications and we are free to extend this for future identification methods. The physical tracking of the individual product is independent of the registration and management of the characteristics of the individual product. Because of the configurability of the terminals the terminology can be independent of the meaning of the data (which also forms a risk!). By the application of services in the data system a response time of at most 200 ms can be guaranteed in internal messaging. By using a monitoring tool for the messaging traffic (current traffic and traffic history) the system behaviour can be analysed both by the employees of the customer as by the employees of RBK.

To solve the organisational issue of “dividing labor and achieving coordination among them” (the terminology of Mintzberg) one aspect was crucial: mutual understanding and mutual trust as the foundation for mutual adjustment. Our past had taught us that a lack of cooperation often was due to a sense of ownership and responsibility of individual developers, and as a consequence a strong striving for independency. Someone wants to be able to solve problems in ‘his’ system and he does not want to depend on things of which he does not have a good grasp. This is exactly where the problem lies between different departments: they represent separate knowledge domains that do not sufficiently understand one another. This problem cannot be solved by integrating everything. This problem can however be solved by (1) clearly delineating the systems and responsibilities, (2) giving all parties sufficient overview of the system as a whole and the interactions between the components, and (3) giving all parties sufficient confidence that everything will work in practice even though there is no single person with an in-depth knowledge of all the details.

The preparation together with the customer was part of the process of building trust. This was a taxing process with an exhaustive analysis from all the information products (interfaces, screens, control actions, reports) back to the origin of the data and especially to the internal encodings of our subsystems that were to be created. After this analysis we had the system fully specified and testable on paper; and we were able to answer all questions from the practitioners at the customer and from within RBK. N.b.: a happy circumstance for this kind of system is that full analysis was indeed feasible, which is normally not the case.

A second part in the building of trust was an extended period of testing in the office, followed by a period of five weeks of pilot running in the actual production line along the operational system. During the pilot running, differences between the existing and the new system were subject to daily analysis. Eventually, the new system was put into operation a few days before the scheduled date, and needed very little aftercare.

# 4 THEORY & PRACTICE

The question how systems function has always interested me. For organisations, the assumption during my studies and the first years afterwards was that organisation theory should be the entry point to understand its inner workings. A definition like "organizations are (1) social entities that (2) are goal directed, (3) are designed as deliberately structured and coordinated activity systems, and (4) are linked to the external environment" (Daft, 2001) supports this assumption. However, I was unable to reconcile this theory with my practical observations in a satisfactory manner. The organisation of quite a few of our most successful customers are characterised by a flat, informal organisation, much more evolved over time than designed. Mintzberg's work The Structuring of Organizations" (Mintzberg, 1979) shed some more light on the understanding of real-world organisations ("the structure of an organization can be defined simply as the sum total of the ways it divides its labor into distinct tasks and then achieves coordination among them"). In comparison to the definition of Daft this definition leaves out the 'design' element; and it leaves much more room for developing patterns of specialisation and coordination.

The major shift came with the insight that the approach should be reversed. Instead of starting an analysis with the organisation of an enterprise, using the organisation as a basis to look at the business processes and finally looking at the environment, I had to start off with the environment. The rationale of an enterprise is after all the successful production and selling of products on its markets. Does it fail to do so, then the enterprise ceases to exist. This is why the analysis of an enterprise ought to start with its markets and products. The business processes then represent the actual behaviour of the enterprise in which the products are marketed and produced. Finally, the formal and informal organisation serves to stabilise the business processes in order to warrant the effectiveness and efficiency in the short term and the continuity in the long term. This last approach also combines much more easily with the mixture of societal norms and the informal development of patterns that characterises the social world. This reversed approach is warranted in various ways by economists like Coase (Coase, 1937), Kay (Kay, 1993), and De Geus (De Geus, 1997).

For the approach of enterprise information systems I needed a similar break with conventional modes of thought. No longer do I consider the computer-based information system as the starting point and goal of information analysis. The information system of an organisation in a broad sense encompasses all information to and from business processes and the computer-based information system is no more than a part of it. Computer systems should be viewed as just an instrument to support the effectiveness and efficiency of the business processes, and not as the only way of processing information in an organisation. This approach regularly clashes with the dominant view that has as its ideal that the information system within the computer should be a single whole in which all information is recorded in a centrally organised manner and where information has the same meaning to each of its users. In the majority of cases it is possible to demonstrate to the customer that this is an illusion, preferably by using examples from practice using their own processes. The bottom line of an information system is that the people and systems in the organisation (1) must have the information needed for their role in the business processes, (2) must generate information from their work for the subsequent business processes. It is a practical matter which information channels are best suited to record and communicate which kind of information.

Over the years I have started to pay increasing attention to the way in which people handle information. The basis for this lies in the research by De Groot into the thinking of chess players (De Groot, 1965). De Groot shows in his study Thought and Choice in Chess that a major part of the strength of the expert is found in his perception of the situation. An expert does not see anything that a novice does not see, but he sees it differently. Research by Weiskrantz (Weiskrantz, 1997) shows that an essential part of our perceptual processes are unconscious. This agreed with my experience in practice that experienced people react to sometimes seemingly small and insignificant deviations from habitual patterns and that it is at times hard to indicate why and based on what they react. For the design of information systems this means to me in practice that the adequate recording and presenting of the events on the shop floor to this kind of people is an important challenge. The goal of our information systems should be that the perceptive field of our users is enlarged, and not narrowed down by irrelevant and rigid categorisation of data that so often comes with computer systems.

In information system projects lots of translation issues are involved. As a specialist in our market we have learned which questions to ask, how to interpret the answers, and we have learned how to translate patterns into models and solutions. At the same time, we have learned to search for the specific details which make a company unique and which represent its competitive power on its market. One of the greatest risks as an external adviser is to reduce the situation of the customer to nothing more than an example of a predefined pattern. For information systems, heterogeneity and not homogeneity should be the norm, as is specified in the Reference Model for Open Distributed Processing (ISO/IEC1998).

In a project, the customer is transferred from an existing situation to a new situation. In the implementation of a new information system the individual employees should be guided by showing them how the same underlying processes are handled in new ways. Continuity and change must be shown. Last year, I discussed these matters a little with a researcher in Translation Studies, a field which might contain some useful theoretical views about this subject (Marais, 2014).

## 5 CONCLUSION

The combination of practical and theoretical work has always been a fruitful way of working for me. The problem of research in business is always how to get access, and how to evaluate situations. With my background at RBK I was in the very fortunate position to be able to observe and participate in many business situations.

Part of my theoretical background is in semiotics and in the philosophy of language. Talking about these theories does not in itself help in business analysis, but it certainly contributes to a sensitivity for meaning and interpretation issues. That sensitivity has greatly helped me in analysing processes and in looking for solutions. Respect for the heterogeneity of reality and avoiding reductive solutions is a result of both my practical work and my theoretical studies.

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# SHORT PAPERS

# Comparing DEMO with i_Star
## *In Identifying Software Functional Requirement*

Tarek Fatyani, Junich Iijima and Jaehyun Park
*Graduate School of Decision Science and Technology, Tokyo Institute of Technology, Tokyo, Japan*
*{fatyani.t.aa, iijima.j.aa, park.j.ai}@m.titech.ac.jp*

Keywords: Demo model, Enterprise engineering, Requirement engineering, i* (i-Star) framework, Goal modelling.

Abstract: Information systems development (ISD) has encountered a variety of challenges in terms of identifying the requirements among multiple stakeholders. This is due to the complexity of the related information. Therefore, an abstract model of the enterprise is needed to focus on people and their needs before developing any information system. To respond to this need, new modeling methodologies that focus on modeling the enterprise as a social system have got a wide acceptance. DEMO and i* are an example of these modeling methodologies. They focus on modeling the people and the interaction between them. Although DEMO is a based on strong theories, it is not used much as i* in requirement engineering. Therefore, this research compares these two modeling methodology in identifying the functional requirements for developing information system. The comparison is to highlight the strong and the weak part of both modelings. Moreover, this research draws guidelines for improving both methodologies in modeling enterprise as a prior step in developing information system. As a result, the concept of modeling the interaction between DEMO and i* is different. DEMO is more formal inmodeling the interaction rather than i*. Moreover, DEMO models both the structure and the behavior through its different diagrams. But i* does not capture the behavior. In contrast, i* allows to model the non-functional requirements, too. Sometimes it is useful to analysis them during the first stages of requirements analysis.

# 1 INTRODUCTION

Current information systems are getting more complex in terms of the number of the stakeholders who benefits from these systems as well as in terms of the related information to be in the system. Therefore, information systems development (ISD) encountered a variety of challenges in terms of identifying the requirements among multiple stakeholders. How can one differentiate between what the users want and what they really need. One of the common problems in requirement analysis is requirements conflicts. Therefore analyzing the requirements is crucial for software development (Mazón, J.N., Pardillo, Juan, 2007). Scoping and requirements engineering are the most important challenges that SMEs faces during information systems development (Silva, Neto, O'Leary, Almeida, Meira, 2014). Therefore, before the requirement analysis stage, an abstract model of the enterprise is needed. This model must describe the essence of the enterprise. It should describe the structure of the organization and its interaction with its environment (Tuunanen, Rossi, Saarinen,Mathiassen, 2007). Failure to do so may lead to a requirement uncertainty (Michalik, Keutel, Mellis, 2014).

In the last two decades, practitioners and researchers seeked an alternative for modeling the enterprise as a social system. This means that enterprise consists of individuals who interact with each other to deliver a particular product or service to the environment.Therefore, new modeling methodologies were developed to model the enterprise as a prior model to any implementation.It has proved that such a modeling with analysis provides benefits at every stage of the requirements engineering process (Jose, Jesús, Juan, 2007). DEMO and i* are good examples of these methodologies. DEMO provides a formal model of the enterprise, including the structure and the behavior.Although DEMO is based on strong theories, it is yet to be used in many real-world scenarios in developing information systems (Kervel, Hintzen, Meeuwen, Vermolen, Zijlstra, 2011). On the other hand, i* is widegly accepted modeling methodolgoy in many fields (Yu, Giorgini, Maiden,Mylopoulos, 2011). In particular it used in modeling the goals of the information system before developoing it. There are many frameworkds for develping the requirements based on i*. It is similar to DEMO in providing a better understanding of the decision-making process and the rationales behind it by providing an abstract model of the enterprise (Átila, Monique, Emanuel, Josias, Fernanda, Jaelson, 2011).

This research aims to understand the difference in popularity of the two methodologies i* and DEMO by comparing them in one real case study. By this comparison, we can highlight the pros and cons of using DEMO. It also helps in developing a framework for developing information system based on DEMO similar to the frameworks that i* has.

As a result of this research, it is clear that DEMO is implemntation independent methodology. But i* is implementation dependent emthodology. This means that DEMO model does not change according to the implementation method. It is up to the designer to select the implementation that fits the enterprise needs. And DEMO model will not be changed before and after the implementation unlike the i* model. However, i* can capture not only the social aspects of the enterprise, but also the rational aspects, too. The rational dependency model of i* can model the processes as they are in the implementation. This is useful for developing the information systems.

The rest of the paper is as follows. First, literature review provides an explanation about i* and DEMO with their recent research in the field of requirements engineering. Second, a real world case study is introduced, then modeled by both i* and DEMO. Third is the conclusion with the discussion about the similarities and the differences between i* and DEMO.

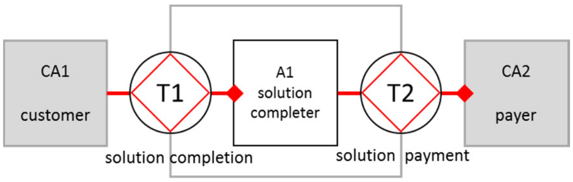
# 2 LITERATURE REVIEW

In this section, the main concepts of DEMO and i* are explained. a running example will be used to explain the way of modeling of DEMO and i*. Where, customers request the enterprise a particular IT solution. And they pay the fees for this service.

## 2.1 The DEMO Model

DEMO, which stands for “Design and Engineering Methodology for Organizations”, is based on PSI (Performance in Social Interaction)-theory.In this theory, an enterprise (organization) is considered as an interaction of social individual subjects. DEMO helps in ‘discovering’ an enterprise’s ontological model, basically by re-engineering from its implementation.The main elements of DEMO models are actor roles and transactions. Any transaction within an enterprise is carried out by an interaction of two actor roles. The first actor role is responsible for initiating the transaction while the other actor role is responsible for executing the transaction (Dietz, 2006).

DEMO consists of four models. The construction model (CM) specifies the structure of the enterprise in relation to its environment, including the transactions, actor roles, information banks and links between them. The process model (PM) specifies the details of the transactions in the CM. Though the CM does not specify a sequence in which the transactions are executed, the PM does while indirectly indicating the timeline. The fact model (FM) specifies the object classes, which consist of a fact kinds and transaction result kinds. The action model (AM) formulates the business rules for executing each process step in the PM.




| transaction kind | product kind |
|---|---|
| T1 solution completion<br>T2 solution payment | P1 Solution is completed<br>P2 the fee of Solution is paid |

Figure 1: CM model of simple case.

Figure 1 shows CM model of a simple case. CM consists of OCD (organization structure diagram) and TPT (transaction product table). Customer requests a solution from IT Department store, which is represented, by the actor role solution completer. This actor role is the executor of T1. Therefore, a small diamond appears at the end of the link to T1. The solution completer then asks for the payment by initiating the transaction T2. The grey rectangle represents the scope of interest (IT Department store). “A” stands for actor role. White actors are elementary actors. And grey actors are composite actor roles. TPT shows the product of each transaction after completion.

In DEMO, the ontology, infology and datalogy levels are clearly differentiated. In the ontology level, actors (human beings) initiate and execute transactions that result in original facts, for example, purchasing. At the infology level, transactions only manipulate information from one shape to another, for example, calculating salary. At the third level, datalogy, transactions store and retrieve data without any manipulation. DEMO provides a high level of abstraction of the enterprise.

DEMO has already proved its powerfulness in capturing a high abstract conceptual model of the enterprise. DEMO models can be used in process re-engineering as well in enterprise engineering. However, using DEMO models in a stage prior to requirement engineering for developing information system is still in progress. A few frameworks are developed for developing enterprise information system based on DEMO. Nevertheless, very few real world case studies applied the frameworks. Therefore, more real world case studies are needed to enhance and justify those frameworks. For example, DEMO processors that compile and execute the DEMO models have been developed (Kervel, Dietz,Hintzen, Meeuwen, Zijlstra, 2012).

On the other hand,i* model is a previously established framework in requirement engineering for developing information systems (Pandey, Suman, Ramani, 2010). By comparing i* with DEMO, we can thus formulate a framework for developing information system based on DEMO models.

## 2.2 i* (i-Star ) Framework

The i* (i-star) framework is one of the most widely adopted modeling approaches by several communities (e.g., requirements engineering, business process reengineering, organizational impacts analysis and software process modeling). It is a goal- and agent-oriented modeling and reasoning framework that defines models that describe the systems with the environments in terms of intentional dependencies among strategic actors (Pandey, Suman, Ramani, 2010). It is used for comparing many different scenarios for the same system by changing the dependencies between the agents (Liu, Yang, Wang, Ye, Liu, Yang, Liu, 2014). There are two different models: (1) the strategic dependency (SD) describes information about dependencies and (2) the strategic rationale (SR) defines the actor details. The SR model complements the information provided by the SD model by exploiting internal details of the strategic actors to describe how the dependencies are accomplished.

Figure 2 shows SD of the same simple case that represented in CM model in DEMO. Actors are represented by circles. Customer asks the solution provider an IT solution. Here, the solution represented by oval to show that it is goal type. The solution provider asks the payment from the customer. Payment is represented by a rectangle because it is considered a resource type.

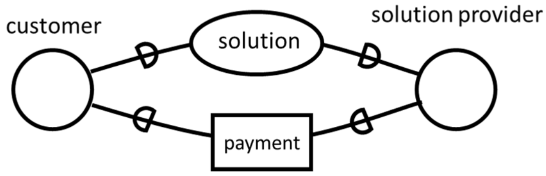



Figure 2: SD of a simple case.

In i*, there are four types of dependencies that are characterized according to the dependum. The dependum can be a soft-goal, a goal, a task or a resource. Soft-goals are associated with non-functional requirements (NFRs), while goals, tasks, and resources are associated with system functionalities (Castro, Lucena, Silva, Alencar, Santos, Pimentel, 2012).

# 3 CASE STUDY

The following passage describes a case study modeled by both DEMO and i*. Those models will be used later for specifying the requirements to develop information system. This section consists of four parts. First is a textual description of the case study. Second is explaining the objectives of developing the information system. Third is the DEMO model with its explanation. Fourth is i* model with its explanation.

## 3.1 Background of the Selected Case

SMA offers its customers IT solutions by developing software based on the customer's needs or by providing consultation. SMA is a project-based company. Every project belongs to one client who may have more than one project with the company. The employees do not form a structure based on the organization chart, rather they are flexible based on the projects they have. This flexibility allows the company to respond quickly to the changes in the market.

In every project there is one project manager leading a team of developers. The project manager is responsible for planning the project, as well following it to completion.

Based on the project, different person from project manager would be responsible for delivering the product to the customer. This person may also be responsible for taking care of the payment from the

customer. Otherwise, the project manager does the delivery and receives the payment from the customer. When a new project arrives, the project manager begins by planning the project.
As a result of the planning, a list of tasks with their schedules is made. After breaking down the project into tasks, the project manager assigns the tasks to the developers. During the execution of the project, new tasks may pop up. Therefore, every developer may assign a new task to himself/herself or assign it to the other developers. All the tasks must be recorded in the information system to be developed. This is very important to follow up the completion of each task.

The project manager controls the completion of the tasks every week. The project manager then looks at the completed tasks and the remained tasks. He/she reassigns the tasks from developers with work overload, to those who have less work. This provides a work balance for every developer, to allow efficient project completion. At the same time, the manager may control the execution of the tasks by prioritizing them according to their importance.
Employees receive their salaries based on their work time. Therefore, they record the time for completing every task they do. In addition, at the end of the month, the accountant calculates the work time for each employee. For each employee, there is a specific hourly salary rate. Based on this rate, the actual payment is calculated. The salary is the sum of work time multiplied by the salary rate plus the reward.

Employees may ask for bonuses or other rewards. This is done after evaluating their performance. The project manager analyzes the performance of all employees based on their task completion rate. Moreover, based on the performance analysis, the salary rate may increase or a reward for a particular project may be given.

Employees are free to choose their time to work, i.e., day or night, as long as the projects are proceeding as scheduled. This flexibility gives them responsibility for their time.

To keep the level of the skills in the company up to date, SMA frequently hires new highly qualified developers.

## 3.2 Objectives of IS to be Developed

The information system to be developed has three main objectives.

The first objective is to follow up the execution of all the projects. During the execution of the project, the project manager needs to know the statutes of the tasks and the workload for each employee. This helps to follow up on the project to meet timeline, quality and cost limits.

The second objective is automation. Because the salary of each employee is based on the tasks that are executed by the employee, there are many calculations needed. To reduce the cost of these calculations, they should be automated.

The third objective is the performance analysis. To analyze the performance of each employee, a record of his/her achievements should be archived. Because each task is associated with an execution time, the productivity of the employee may be estimated.

## 3.3 The DEMO Model

Based on the description in the previous two paragraphs, the DEMO model of SMA can be constructed as follows. Because of pages limitations, only the organization construction diagram (OCD) of the construction model (CM) will be detailed. The unit of business service of SMA is the provision of an IT solution to the customer. Therefore, the first transaction to be identified is the (T1) project completion. The customer (CA1) initiates this transaction by requesting an SMA employee to provide an IT solution. This employee will be called the project completer (A1). A1 initiates three transactions: (T2) project fee payment, project planning (T3) and task completion (T4). It must be said that T4 cannot be requested before the plan of the project is done. Since the project manager controls the execution of the plan, then he or she is taking the role of task manager (A5). This actor initiates and executes periodically (every week) the transaction task management (T5). The execution of this transaction leads to change the project plan. Therefore, plan revision transaction is needed (T6). To model the salary and the reward that are mentioned in the description, salary payment control (T7) and reward management (T10) transactions are needed. To execute T7 we need to calculate the salary. Because there is no original fact in T8 (only calcluation), then it is infological transaction (green). To execute T10, we need two sub transactions, reward decision making (T9) and employee evaluation (T11). Based on the previous paragraph that describes the objectives of the information system to be developed, the scope of the information system is shown by a green rectangle. The customer

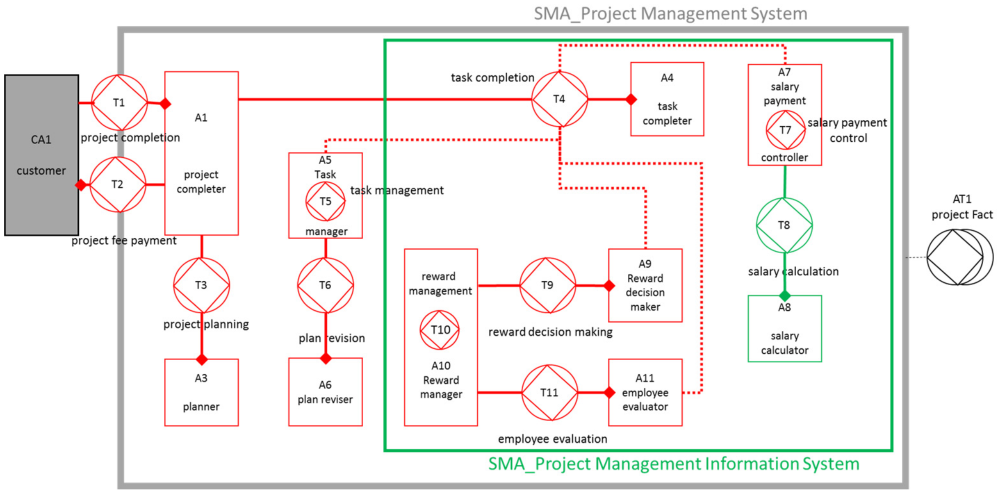



Figure 3: Actor transaction diagram of SMA.

has no relationships with the information system. This is because SMA prefers to always communicate with the customer directly to form good human relationships. The OCD of the CM is shown in Figure3.

## 3.4 i* Model

Because the objective of the model is to develop an information system, then only the actors who are involved in the system will be modeled. In i*, unlike in DEMO, we starts by modeling the actors. There are three actors: manager, employee and accountant. The manager has a dependency relationship with the employee by asking him/her to achieve a particular task. The dependency is of the task type because it is a task. The employee has two dependency relationships: salary and reward. Because they refer to the money to be given from the accountant to the employees, both dependencies are of the resource type. To give the reward, a performance analysis is needed. Therefore, the accountant depends on the manager to do the performance analysis for the employee before giving the reward. This is a resource type dependency. The strategic dependency (SD) model is shown in Figure 4.

For each actor in the SD, there is a rational dependency (RD) model. In this research, only one RD will be modeled. In Figure5, the RD for the manager is shown. The RD shows the internal tasks that the actor performs to respond to the external dependencies of the other actors. In SMA, the manager controls the tasks for each employee. The task can be decomposed into two tasks: assigning a task and releasing a task. These two tasks influence the soft-goal balanced load. At the same time, controlling the tasks is required for evaluating the achievement of an employee. The result of the evaluation is the performance analysis, which is delivered to the accountant.

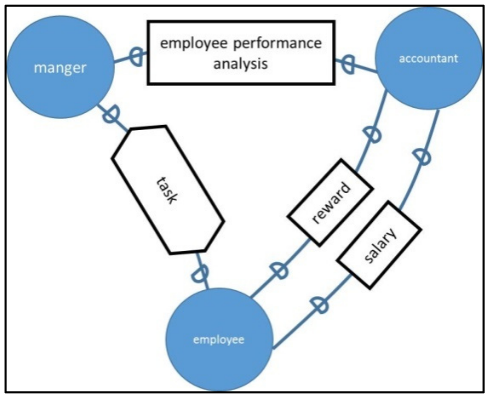



Figure 4: Strategic dependency model of SMA.

# 4 DISCUSSION AND CONCLUSION

## 4.1 Discussion

First, Both DEMO and i*are social modeling methodologies. In their models, enterprise consists of actors (actor role in DEMO and agent in i*) that interact with each other through relationships (transaction in DEMO and dependency in i*). However, the concept of actors and relationships are different. In i*, humans are modeled by an actor with concrete names, for example, manager, employee and

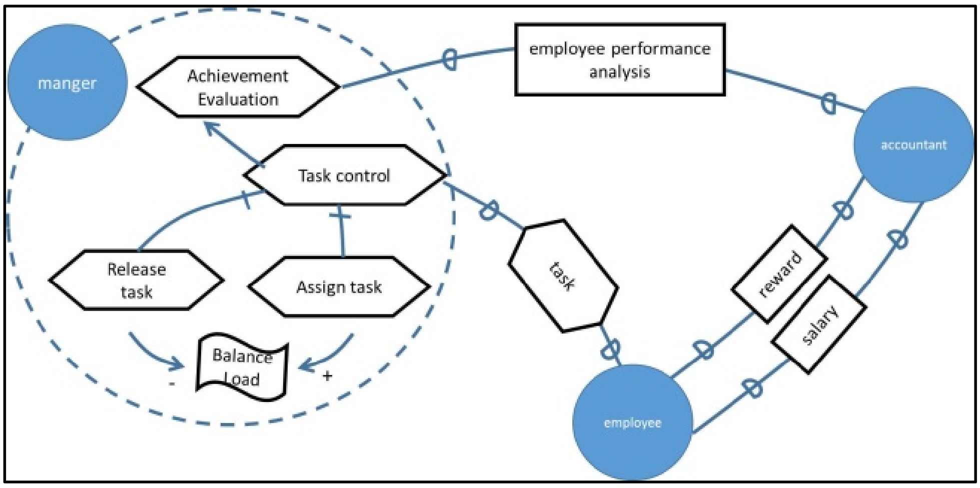



Figure 5: Rational dependency model of SMA.

accountant. However, in DEMO, it is more abstract such as planner and task controller. After presenting these two models to the stakeholders, it was more easy for them to understand i* model than DEMO. This is because i* uses more concrete roles that are familiar to the stakeholders. The following table matches the actor role in DEMO with the actor in i*.

Table1: Actors in DEMO and i*.

| DEMO actor role | i* actor |
|---|---|
| task manager, plan reviser, reward manager, and employee evaluator | Manager |
| Task completer | Employee |
| Salary payment controller, salary calculator, and reward decision maker | Accountant |

From the Table 1, we can see that every actor in i* can be broken down into actor roles in DEMO. Therefore, a composite actor role can be used in DEMO to make it easier to be understood. Every composite actor role can be later decomposed into its elementary actor roles. This facilitates discussing the model with the stockholders.

Second, there is a difference between a transaction in DEMO and a dependency in i*. In DEMO, transactions are divided into ontological, infological and datalogicalcategories according to the abstraction level. The differences between them are clear by definition. Whereas in i*, the dependency is divided into goal, resource, task and soft-goal. However, the difference between goal, resource and task is not clear. This looseness may not be important in some situations. However, in others situations, such as model-driven development, it is very important (Lidia, Xavier, Jordi, 2014).For example, in our model, both reward transaction and salary transaction are modeled in i* as a resource. However, task completion transaction in DEMO is modeled in i* as a task. Therefore, no automatic transformation between transaction in DEMO into i* could be done.

Third, i* is capable of capturing the rational aspect of the system by RD model. Agent in i* could be decomposed into rational elements. This facilitates the implementation by automating them. However, DEMO is considering only the social part of the system. This makes it difficultfor implementing the system in later stages.

Fourth, i* models soft-goals. This is useful for modeling the nonfunctional requirements in the early stages. Service quality and service speed are examples of nonfunctional requirements. But DEMO considers only the functional requirements.

Fifth, DEMO has four perspective models (construction, process, fact and action) that captures a holistic view of the enterprise. This is very important in developing any information system (Figueiredo, Souza, Pereira, Prikladnicki, Audy, 2014). However, i* does not have equivalent to fact and action models of DEMO.

## 4.2 Conclusion

This research compares between two modelling methodologies named DEMO and i* in modelling enterprise as a prior stage of requirements analysis. By the comparison between DEMO and i*, both of them are social modeling methodologies. They focus on human and human interaction in their modeling. DEMO is implementation independent. Therefore, the DEMO model does not change before or after implementing any IT solutions. However, i* is implementation dependent methodology. DEMO provide more formal and rigour model of the enterprise. That makes it a good potential modelling methodology to understand the enterprise before implementing any IT solution. On the other hand, i* allows us to capture both the rational and the social aspect of the enterprise. The rational aspect is important in developing any information system. Therefore, DEMO should be extended to capture the non-social aspect, too.

There are some frameworks for developing information system based on i*. Since we showed the strength of DEMO, the next step is to develop such a framework like the i* has. Another point to be considered in the future is extending DEMO to capture the rational aspect of the enterprise like i*. This is important for developing information systems.

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# A Pragmatic Risk Assessment Method Supported by the Business Model Canvas

Diogo Proença[1,2], Ahmad Nadali[1,2] and José Borbinha[1,2]
[1]Instituto Superior Técnico, Universidade de Lisboa, Lisbon, Portugal
[2]INESC-ID, Lisbon, Portugal
{diogo.proenca, ahmad.nadali, raquel.bairrao, jlb}@tecnico.ulisboa.pt

Keywords: Risk Assessment, Digital Curation, Business Model Canvas.

Abstract: This paper presents a pragmatic risk assessment method based on best practice from the ISO 31000 family of standards regarding risk management. The method proposed is supported by established risk management concepts that can be applied to help a data repository to gain awareness of the risks and costs of the controls for the identified risks. In simple terms the technique that supports this method is a pragmatic risk registry that can be used to identify risks from a Business Model Canvas of an organization. A Business Model Canvas is a model used in strategic management to document existing business models and develop new ones. The risk assessment method is then applied to a Civil Engineering Laboratory to illustrate the benefits of such a method.

## 1 INTRODUCTION

The purpose of this research is to make good use of risk management concepts to raise awareness of repository costs of digital curation. Costs are what we have to give up for controls, which in turn are the measures that we have to put in practice to minimize loss or to maximize gain. In that sense, a control is anything we are considering applying to either minimize negative impacts or to take advantage of opportunities to produce value and thus bring gains. However, we must also agree that, in most of the usual digital curation scenarios, it is usually very difficult to estimate the absolute value of an asset. For that reason, we are here ignoring the measurement of value, and focusing only in the identification of controls as the source of costs.

The technique behind this method analyses an archive with the support of a risk registry and is based on Business Model Canvas (BMC). A BMC allows organizations to fill their business model in a visual canvas that allows for easy understanding of their business in nine building blocks. The motivation behind it is to understand both what can positively affect the value propositions of your business (opportunities) and what can negatively affect those same value propositions (risks).

The idea is to identify and understand the risks and their impact (positive and negative) on each of the nine building blocks of the BMC. We demonstrate how the BMC technique can be used in the method above to find risks and then controls for those risks. This in turn makes it possible to estimate the related costs as part of the overall costs of curation. Digital curation "involves maintaining, preserving and adding value to digital research data throughout its lifecycle. The active management of research data reduces threats to their long-term research value and mitigates the risk of digital obsolescence." (DCC, 2014) The main steps done are:

1. Formulation of related risk questions: for each of the building blocks of BMC some questions are provided to facilitate the identification of risks for each of the building blocks.
2. Generic Risks and Controls for the Generic BMC: after the formulation of the risk questions, the next step is to identify the related risks, and then the respective controls.

Generic risks and controls were identified after analyzing the results of the DRAMBORA (DCC/DPE, 2007) report. The risks and controls that better align with the generic BMC model were selected.

The result is a generic BMC, with an associated generic registry of risk questions and common related controls, relevant for the domain of digital curation to cost evaluation. The pragmatic method was applied to estimate costs of curation focusing on risks and controls to three case studies: two data archives and one web archive. However due to space restrictions this paper focus on just one case. The other cases are available at http://4ctoolset.sysresearch.org.

In conclusion, our contributions here proposed for the digital curation problem are:

- A pragmatic method for risk assessment, based on the main references from the risk management domain;
- A generic BMC for the business of an OAIS repository: This BMC can serve as template for organizations where digital curation has an important role, which can make local instances of it;
- A generic risk registry for scenarios of OAIS repositories, created after analysing DRAMBORA (DCC/DPE, 2007) and comprising.

This paper is structured as followed. Section 2 presents the related work on the topic of the paper. Section 3 details the method used to extract and identify risks based on a BMC of an organization. Section 4 presents the generic BMC for Digital Curation based on the Open Archival Information System (OAIS). Section 5 details the collection of risks extracted from DRAMBORA. In Section 6, a case study and the application of the method are presented. The paper in finalized by presenting the conclusions.

# 2 RELATED WORK

In this section we present the relevant related work on the topic this paper addresses, namely risk management and the business model canvas.

## 2.1 Risk Management

The main references on Risk Management (RM) from the International Organization for Standardization (ISO) are:

- ISO Guide 73: Vocabulary for risk management (ISO, 2009);
- ISO 31000: Risk management principles and guidelines (ISO/FDIS, 2009a);
- ISO 31004: Risk management—Guidance for the implementation of ISO 31000 (ISO/TR, 2013);
- IEC 31010: Risk assessment techniques (ISO/FDIS, 2009b).

According to those sources, organizations (that find RM relevant to their governance) should define an internal RM process taking as a starting point the generic method proposed in ISO 31000 (ISO/FDIS, 2009a). IEC 31010 catalogues a set of techniques for risk assessment (ISO/FDIS, 2009b).

Controls are measures implemented by organizations to modify risk that enable the achievement of objectives. Controls can modify risk by changing any source of uncertainty (e.g. by making it more or less likely that something will occur) or by changing the range of possible consequences and where they may occur." (ISO/TR, 2013)

So, even if we are not following a specific RM method as part of the governance framework of a repository, we cannot avoid having to deal with the identification of risks and controls. However, as a complete RM methodology can be complex and expensive to implement, we are here proposing a simplified method that can be used at least for a preliminary phase of costs estimation. If, after the application of this method, the stakeholders of a repository feel the RM principles are valuable for the governance of their case, and it is worthy to consider a proper and full RM method, then at least these preliminary results can be reused for that purpose.

The definitions for risk management are defined in the ISO Guide 73. (ISO, 2009) Figure 1 provides a view of Risk Management as a conceptual map.

## 2.2 Business Model Canvas

The Business Model Canvas (BMC) is a model used in strategic management to document existing business models and develop new ones. (Osterwalder, 2009) A BMC comprises nine building blocks that describe an organization, as illustrated in the Figure 2.

The BMC is designed to "allow a group of people to fill it in through brainstorming sessions and thus create a relevant understanding of their business model." (Osterwalder, 2009) At the end of such a process each block must have at least one shared assumption about the business. It is even possible to develop more than one BMC in order to represent different, alternative views of the business.

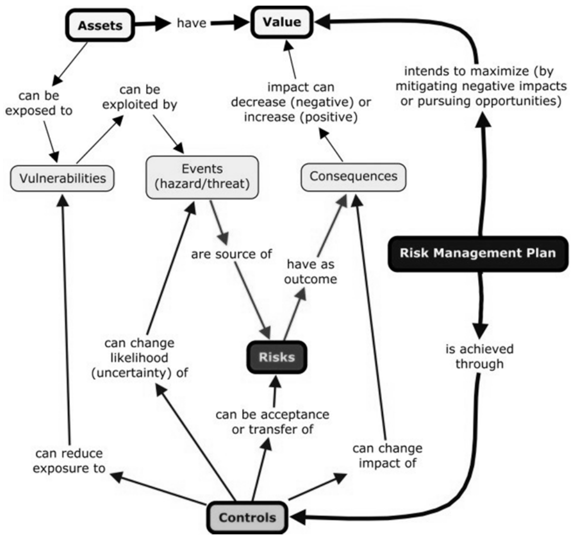


Figure 1: Conceptual map showing controls as the cost entities in a risk management perspective.

The BMC was first proposed in Osterwalder thesis (“The Business Model Ontology—A Proposition in a Design Science Approach”). (Osterwalder, 2004) After that, several authors developed or adopted this canvas approach for other purposes, such as, the Lean canvas (LeanStack, 2014). In the meantime it has been suggested that doing a BMC exercise is already in some sense performing a risk assessment (Parrisius, 2013) (McAfee, 2013).

| | | | | |
|---|---|---|---|---|
| Key Partners | Key Activities | Value Propositions | Customer Relationships | Customer Segment |
| | Key Resources | | Channels | |
| Cost Structure | | Revenue Streams | | |

Figure 2: The generic structure of a Business Model Canvas.

Some authors have gone even further and proposed the hypothesis that the BMC concept can even be extended to support a pragmatic risk analysis. This is illustrated in (Schliemann, 2013) where the author scopes the business model risk canvas. The motivation behind it is to understand both what can positively affect the value propositions of your business (opportunities) and what can negatively affect those same value propositions (risks).

The idea is to identify and understand the risks and their impact (positive and negative) on each of the nine building blocks of the BMC, as well as the risk appetite of the stakeholders upon which a business depends. Stakeholders in this context can be regulators and investors. There is a huge body of knowledge from the risk management community on how to assess and measure risk through analytical tools but this new technique fills the need to introduce risk assessment at a higher level, scoping it visually in consideration for each of the building blocks of the BMC.

When applying this technique to identify the risks and their impact there should be a series of risk-related questions for each of the nine building locks of BMC. Simple examples of these questions

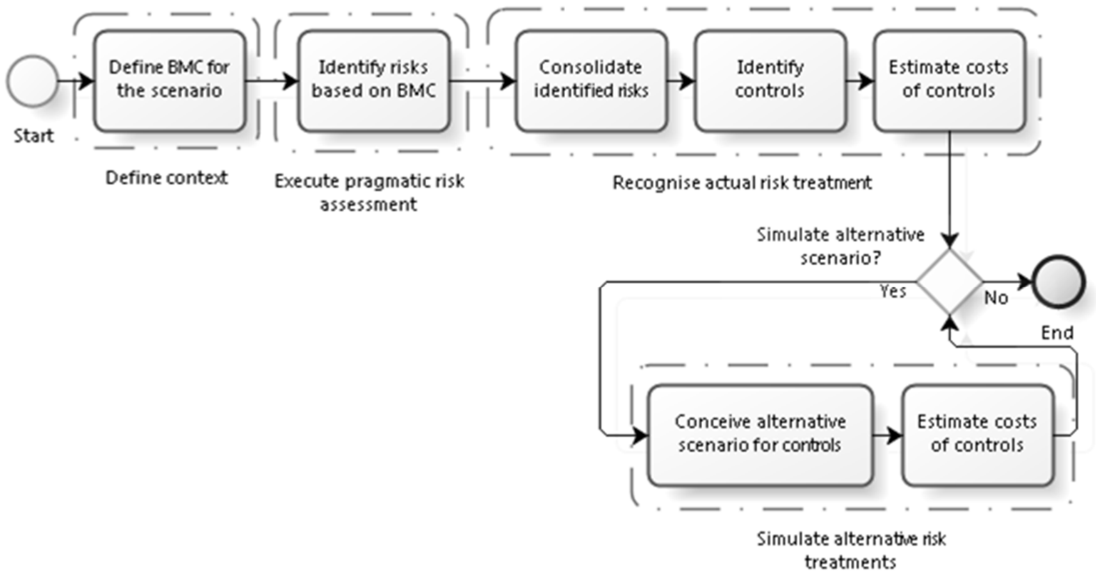


Figure 3: BPMN diagram of the pragmatic method to estimate costs of curation focusing on risks and controls.

are proposed in the original business model risk canvas, but for real use these should be scoped for the business in question.

## 3 A METHOD TO IDENTIFY RISKS BASED ON A BMC

This section describes a method for estimating costs of curation in two different scenarios:

- "Current" scenario, where the costs of controls already exist in the repository as a means to reduce the impact of a consequence of a risk, change the likelihood of an event, or reduce the exposure to a vulnerability;
- "Future" scenario, where the costs of controls do not yet exist, but where repository managers are able to consider alternative scenarios of repository governance.

The foundations of this method draw from relevant sources, such as the ISO 31000 standard and the Business Model Canvas (BMC).

The core stages of the method are:

1. Define the Context: Define the requirements of the main elements: the organisation (mission, etc.); the assets (data and services), and the external stakeholders—and, for each of these elements define the BMC for the scenario.
2. Execute a Pragmatic Risk Assessment: Use a risk repository, or consult experts, in order to identify relevant risks associated with the BMC.
3. Recognize Actual Risk Treatment (the "Current" scenario):
   - o Consolidate the risks identified (mainly, to detect repetitions and overlaps). Note: This is probably the best stage to identify potential positive impacts (if the identification of positive impacts is desired).
   - o Use internal information, and (if necessary) also consult a risk repository or experts, to identify the controls to apply for the consolidated risks.
   - o Estimate the costs for these controls (the ideal is to calculate these costs precisely, however, best estimates can also be useful).
4. Simulate Alternative Risk Treatments (an optional activity, to be executed as many times as needed, to explore possible alternative "Future" scenarios):
   - o Use internal information, eventually also consulting a risk repository or experts, and according to the businesses strategic view and governance rules, conceive alternative scenarios for controls of the identified risks. Note: This is probably the best stage to explore

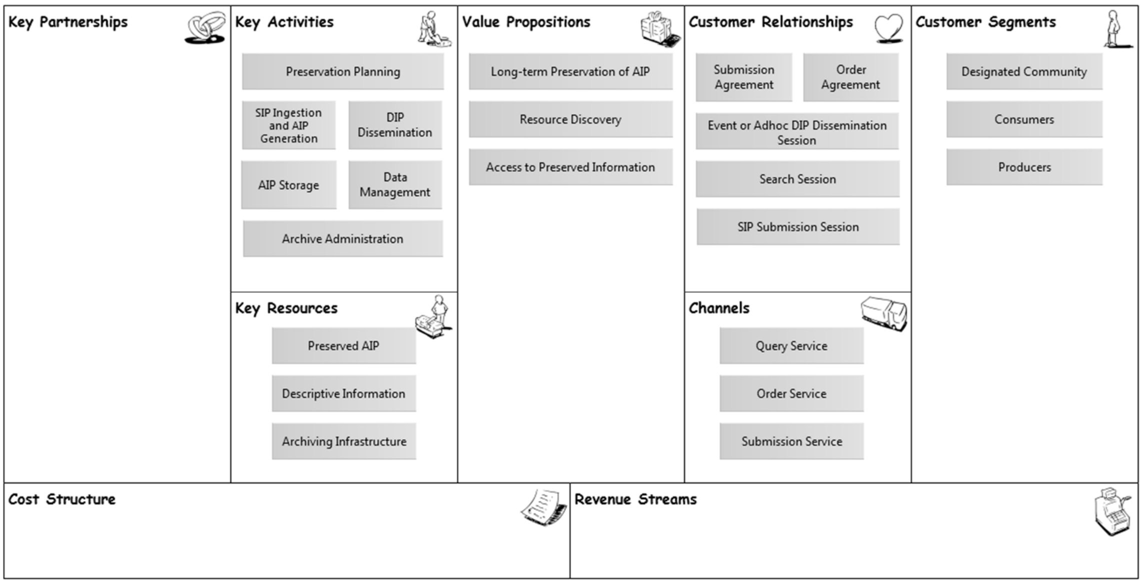


Figure 4: The generic BMC for OAIS.

opportunities to exploit positive impacts (if the exploitation of positive impacts is desired).
- Make your best estimate for the costs of this new scenario.

Steps 1 to 4 are illustrated in Figure 3 in the form of a business process diagram (expressed in the BPMN – Business Process Modelling Notation language).

# 4 GENERIC BMC FOR DIGITAL CURATION BASED ON THE OAIS

The purpose of this BMC is to represent a generic Business Model that can be applied to Archives, serving as a template that can be instantiated to specific organizations. To develop the OAIS BMC the recommended practice CCSDS 650.0-M-2 from the Consultative Committee for Space Data Systems (Magenta Book) was used. The objective of this BMC is that organization which have archival as one of its core services can use this BMC to build its business model by instantiating it to their context.

Figure 4 depicts the generic BMC based on OAIS. For details on the BMC please visit http://4ctoolset.sysresearch.org, under OAIS Template. The BMC uses definitions from OAIS (CCSDS, 2012).

# 5 RISKS AND CONTROLS REPOSITORY

Generic risks and controls were identified after analysing the results of the DRAMBORA (DCC/DPE, 2007) report. The Digital Repository Audit Method Based on Risk Assessment (DRAMBORA) represents an effort to conceive criteria, means and methodologies for risk assessment of digital repositories. The risks and controls were selected and can be found at the Holirisk tool in http://4ctoolset.sysresearch.org a sample is provided in Table 1

Table 1: Generic risks and controls identification.

| Id | Generic risks | Generic controls |
|---|---|---|
| R1 | Business fails to preserve essential characteristics of digital assets | Define main characteristics of digital content for information preservation |
| R2 | Business policies and procedures are inefficient | Document and make available business policies and procedures |
| R3 | Enforced cessation of repository operations | Plan for continuation of preservation activities beyond repository's lifetime |
| R4 | Activity allocates insufficient resources | Use mechanisms to measure activity efficiency in terms of allocated resources, procedures and policies |
| R5 | Community requirements change substantially | Identify, monitor and review the understanding of the community requirements and of the repository objectives |
| R6 | Community feedback not received | Use mechanisms (e.g. email, surveys) for soliciting feedback from repository users community |
| R7 | Community feedback not acted upon | Define policies to acknowledge community's feedback |
| R8 | Loss of key member(s) of staff | Appoint a sufficient number of appropriately qualified personnel |
| R9 | Personnel suffer skill loss | Implement mechanisms to identify ongoing personnel training requirements |
| R10 | Budgetary reduction | Define a financial preservation plan to assure self-sustainability of repository |
| R11 | Software failure or incompatibility | Install software updates |
| R12 | Hardware failure or incompatibility | Monitor hardware performance |
| R13 | Obsolescence of hardware or software | Maintain hardware/software up to date to meet repository objectives |
| R14 | Media degradation or obsolescence | Allocate resources to monitor media storage lifetime and assess potential value of emerging technologies |
| R15 | Local destructive or disruptive environmental phenomenon | Implement physical security measures (e.g. video-record) |

| Id | Generic risks | Generic controls |
|---|---|---|
| R16 | Non availability of core utilities (e.g. electricity, gas) | Define internal means to nullify disruption of service, monitor and review contract agreements of provider's services |
| R17 | Loss of other third-party services | Document and review service level contracts or service commitments with utility provider |
| R18 | Loss of authenticity/integrity of information | Monitor, record and validate integrity of received content |

# 6 CASE STUDY: CIVIL ENGINEERING LABORATORY

The Civil Engineering Laboratory is a public Science and Technology institution, which is subject to Government supervision. Its activity is developed in the various fields of civil engineering and its main assignments are the execution, supervision and promotion of scientific research and technological developments to achieve progress, innovation and good practices in civil engineering. The institution is also responsible for providing an unbiased and suitable scientific and technical support to the executive power, in its governing and regulatory activities. The laboratory undertakes research in the following areas:

- Usage of monitoring technologies to gather observation data and automatic communication systems;
- Risk analysis of dam construction and operation;
- Characterisation and modelling of future deterioration of dams and their foundations.

The BMC presented here (Figure 5) is an instantiation of the generic BMC based on OAIS. For some of the objects in the canvas there are specific case-dependent instantiations of the object between square brackets. For example, if there is an object with Producers [Dam Owners] this means that for that specific case the producers are the dam owners. There are also objects in blue, this means that these objects were not present in the generic OAIS BMC and are specific for the case study depicted by the BMC.

For the other object that do not have neither square brackets nor are depicted in blue this means that these are present in the respective case however there is no need to provide an example as there is no added value in doing so and the OAIS definitions (from Section 4) cover their definition. The details

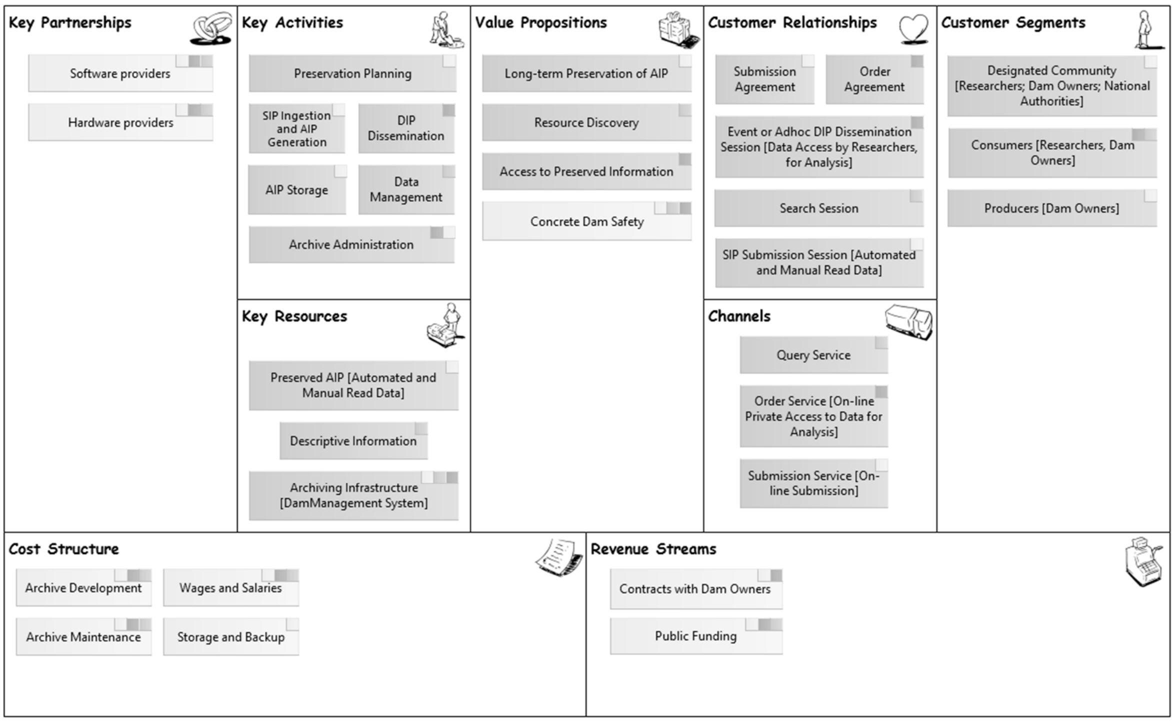


Figure 5: Civil Engineering Laboratory Business Model Canvas.

of the instantiation of the BMC for this case study can be found at http:// 4ctoolset.sysresearch.org.

The risks were identified through the analysis of the BMC for the case study and identified by their Id from Table 1. Regarding the controls for the risks identified, refer to Table 1. For a more detailed analysis of the risks and controls for both the case study visit the Holirisk tool in http:// 4ctoolset.sysresearch.org in the page of the BMC for this case study.

- **Revenue Streams** - Risks related to the worth of a repository business and the value it offers to the community: R10.
- **Cost structure -** Risks regarding the cost to support the repository business: R8; R13; R16; R18.
- **Channels -** Risks related to the communication and dissemination of the business provided by a repository: R6.
- **Customer Segments** - Risk that relates with what the repository should deliver within the community vision: R5.
- **Customer Relationships -** Risks associated with the community that makes use of the repository for their research work: R7.
- **Key Resources** - Risks related to the resources of infrastructure and personnel which sustain the repository business: R15; R3; R8; R9; R11; R12.
- **Value Propositions** - Risks regarding the vision and value of a repository: R1; R2.
- **Key Partnerships** - Selected risks regarding the outsourcing services repository may depend on to deliver the preservation business: R13; R17.

Using Table 1 and the detailed risks and controls from http:// 4ctoolset.sysresearch.org as well as the list of consolidated risks we can identify potential controls for the identified risks.

## 7 CONCLUSIONS

This paper proposed a pragmatic method for identifying risks from a Business Model Canvas which is based in two different scenarios, (1) “Current” scenario, where the controls already exist in the repository as a means to reduce the impact of a consequence of a risk and; (2) “Future” scenario, where the controls do not yet exist, but where repository managers are able to consider alternative scenarios of repository governance.

The foundations of this method make use of relevant sources of literature, such as the ISO 31000 and the Business Model Canvas. The focus of this paper was to present the method as a pragmatic technique, and provide some example for a case study. This paper also provided two tools to accomplish the goals of the method proposed: (1) A generic BMC, which can be used as a template for organization to instantiate to their specific context and (2) A risk registry for digital curation: a registry of risks derived, and also common related controls.

## ACKNOWLEDGEMENTS

This work was supported by national funds through Fundação para a Ciência e a Tecnologia (FCT) with reference UID/CEC/50021/2013, and by the project 4C, co-funded by the European Commission under the 7th Framework Programme for research and technological development and demonstration activities (FP7/2007-2013) under grant agreement no. 600471.

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# Towards Systemic Evaluation of the Business Value of IT

Harri Töhönen, Timo Itälä, Marjo Kauppinen
*Aalto University, P.O. Box 9210, Espoo, Finland*
*harri.tohonen@aalto.fi, timo.itala@aalto.fi, marjo.kauppinen@aalto.fi*

Tomi Männistö
*University of Helsinki, P.O. Box 68, Helsinki, Finland*
*tomi.mannisto@cs.helsinki.fi*

Keywords: IT business value, evaluation, system dynamics, systemic approach.

Abstract: Evaluating the IT business value is a challenging combination of managing the complexity of value phenomenon and the complexity of broad IT impacts. This study analyses the focal characteristics of IT business value evaluation and proposes a research agenda towards systemic evaluation approach. The systemic approach combines concepts of goal driven perspective for benefits, value as a combination of benefits and costs, and the lifecycle view of potential and realised value. These concepts are integrated through system dynamics modelling to understand the IT impact structures and dynamic value creating behaviour emerging from the structures. Finally, systemic approach should be supported by evaluation workflow practices that facilitate seamless data retrieval for the evaluation process, and the integration of evaluation outputs within the organisation.

## 1 INTRODUCTION

The evaluation of the IT business value is an existing challenge and, at the same time, the applications of information technology are becoming more ubiquitous and integrated in everyday business context. Fragmental interpretations of IT business value do not ease these evaluation efforts. IT business value can be interpreted as effectiveness or productivity, or it can refer to cost efficiency or added value.

In order to ensure the desired benefits from the investments, IT cannot be evaluated only as a black box and by relying only on economic measures such as return on investment or net present value (e.g. Martinsons et al. 1999). IT impacts should be studied from the diverse viewpoints of the organisation stakeholders while considering various indirect and complementary factors (Lee, 2001). As an investment, IT differs from the traditional tangible assets. It is not used in a ‘vacuum’ and, as an evaluation target, IT can be approached as a socio-technical phenomenon (Palvia et al. 2001). The evaluation of the IT business value is relevant during the various phases of the IT lifecycle, from the investment calculations to the benefit realisation management during the usage phase, until the decisions on upgrade or discontinuance.

Many authors promote for integrative and holistic approach for evaluating IT business value (e.g. Melville et al. 2004). However, finding the balance between a generic, widely applicable means of evaluation and sufficiently detailed frameworks for providing effective guidance on specific context remains a challenge (Stockdale and Standing, 2006). A considerable body of literature is also devoted to IT business value on industrial and economic level (e.g. Brynjolfsson & Hitt, 1998) but applicable solutions to evaluate individual IT systems are scarce.

The purpose of this paper is to analyse the IT business value evaluation by reviewing the challenges and existing approaches/solutions. We focus on company level and approaches that are applicable at an individual IT system level. The performed literature review is guided by the following research question “*How to characterise the evaluation of IT business value?*”. Building on the evaluation characteristics we propose a schema of conceptual, methods and workflow basis for further research towards systemic IT business value evaluation.

The structure of this paper is as follows: Chapter 2 (*Research methods*) presents the literature review methods. Chapter 3 (*Evaluation of IT business value*) introduces the applicable concepts of value within business system, and continues with a synthesis of the main challenges of IT evaluation. The chapter is finalised by reviewing existing evaluation approaches. In Chapter 4 (*Towards systemic evaluation*), the main findings on IT business value evaluation are summarised, and the basis for systemic evaluation approach is discussed. Chapter 5 (*Conclusions*) concludes the contributions of this study.

# 2 RESEARCH METHODS

This study used a qualitative literature review to identify the challenges, principles and existing solutions to IT evaluation. The main body of IT/IS value evaluation literature was searched from seven widely used academic databases (including ProQuest, ScienceDirect, ACM and IEEE Explore). The searches were completed in November 2011 and scoped to journal article titles, with keyword combinations of ‘IS’, ‘IT’, ‘information system’, ‘information technology’, ‘value’, ‘analysis’, ‘evaluation’, ‘measuring’, ‘measurement’. A total of 912 resulted articles were screened based on their titles and abstracts, after which 53 papers were selected for a deeper analysis. This analysis focused on the literature which elaborated the evaluation aspects at a company as well as at an individual IT system level. Finally 36 papers were included in the concluding analysis.

A parallel literature pool for systems thinking and system dynamics was studied. The core of this systemic literature covered the nominal text books from e.g. Sterman (2000) and Meadows (2008), as well as articles of Journal of System Dynamics Review.

The data analysis phase utilised the grounded theory (Corbin and Strauss, 2008). The coding of the evaluation literature identified for example problems, benefits and costs, methods and frameworks. The coded data was further analysed and higher level data groups were formed. These groups are elaborated in evaluation challenges and approaches sections 3.2 and 3.3.

# 3 EVALUATION OF IT BUSINESS VALUE

## 3.1 Value Perspectives

Our unit of analysis is an individual IT system that is evaluated as part of a company’s business system. At a general level, the IT business value is defined as the contribution of IT to the company performance (Tallon et al. 2000; Melville et al. 2004). Performance may mean effectiveness in meeting the business system purpose and goals with the economic worth as the ultimate judgment of success for the profit making companies. The economic worth is quantified by measures such as return on investment (ROI), internal rate of return (IRR) or paypack time (Martinsons et al. 1999). However, using only the traditional economic measures for valuing IT is easily insufficient due to the broad scope of IT impacts and the attributability challenges when linking the impacts with benefits and costs.

In this paper we define value as an outcome of comparison between benefits and costs. For this, both benefits and costs have to quantified, but not necessarily in monetary terms. The relevant units for the quantification depend on the commensurability needs of the chosen performance evaluation level. Obviously, monetary units are widely commensurable while the index - benefits per costs relation - can be useful for company internal purposes.

The IT impacts aggregate and disperse through various business processes (e.g. Mirani and Lederer, 1998; Melville et al. 2004). In order to understand the multidimensional impact chains of IT, we should be able to link value creating factors to each other at multiple levels:

- **Individual**: benefits and costs as realised by the employees utilising IT in their daily tasks.
- **Organisational**: benefits and costs as realised at process level, e.g. process efficiency as input/output ratio.
- **Business**: benefits and costs as realised at business outcome level, e.g. productivity, sales or profitability, economic worth.

The above mentioned three levels serve as an example of means-end structure where the lower level goals in the hierarchy act as the means to achieve the higher-level goals as ends. This means-end chain theory is widely applied in customer value research to understand the structures and factors affecting the value formation (e.g. Gutman, 1982). Similar structuring is also exercised within IS research, for example Benefits Dependency Network to diagnose IT investment business cases (Peppard et al. 2007).

In order to better understand the temporal challenges of valuing IT impacts, next we investigate 'locus of value'. In customer value research, locus of value is used for separating the benefit realisation as a phenomenon from the locus of explicitly measuring the reflection of phenomenal value. Ng and Smith (2012) discuss phenomenal consciousness (P-C value) vs. access consciousness (A-C value). P-C value is "*creation of value in context that is phenomenal, the raw experience of creating value (goodness) in interactions around the experience*" while A-C value exists "*in the perception, introspection and memory (or imagination) of P-C value before (ex ante) and after (ex post)*".

From the value evaluation point of view, locus of value relates to: 1) the delay between P-C and A-C value, i.e. the delay between benefit realisation in the context and the benefit and/or value measurement or quantification, 2) how well we are able to link the root P-C value to the A-C value that is evaluated at different levels of the business system. In IS research, locus of value is discussed together with the levels of analysis. Within the IT impact chains, locus of value is considered together with the question of how well the measures distant (e.g. economic measures) from the value creation event can actually address the first order impacts at individual employee or business process levels (Barua et al. 1995; Davern and Wilkin, 2010). The distance between the first order impact and the measurement point can be both cause-and-effect structural distance or it can be a time distance as a delay between the event and its measurement.

Davern and Kauffman (2000) discuss locus of value within the scope of the IT lifecycle. Locus of potential value defines the baseline for the expected value before the IT investment while locus of realised value is relevant after the investment. Locus of potential or realised value is not a single spot in time and place but it occurs at multiple levels of analysis, being a summation of multiple loci of value from different levels of analysis, including for example individual, work group and process levels.

## 3.2 Challenges of IT Evaluation

In general, the evaluation of IT impacts is described as 'complex' and 'multidimensional' (e.g. Lee, 2001). In the next paragraphs we elaborate the main challenges and rationale behind these broad descriptions (see Table 1 for the summary).

**Focus and Volume of IT impacts**

We start with two background factors: the *focus of IT* and the *nature of business system*. Our evaluation is scoped to a single company with a specific IT system as an element of a socio-technical business system. The business system includes other elements such as organisational structures, tasks and process hierarchies, goal hierarchies and different interpretations of value. IT impacts traverse through the business system, either broadly with wide effects or with more focused and narrow contributions. The broadness depends on the interrelation of the IT usage and focus with company goals and functions: the closer the focus of IT with strategic and transformative goals, the broader the IT impacts are when more employees, their tasks and business processes are supported by IT. The focus of IT together with the nature of business system reinforce the *volume of IT impacts*. The volume reflects the high number of IT's direct and indirect touch points with its surrounding business system.

**Complementarity**

Complementary factors are non-IT issues that affect how well the desired benefits and costs are realised (e.g. Dedrick et al. 2003). The examples of complementary factors include management practices, user skills and process maturity. Due to the complementary factors, the same IT in different organisational contexts produces different outcomes (Davern and Kauffman, 2000). We argue that complementarity is largely a practical embodiment of a business system being a socio-technical phenomenon. Further, the broader the focus of IT within the business system the more significant is the role of the complementary factors.

**Traceability for causes and effects**

The volume of impacts together with complementarity complicate the traceability of IT impacts within the business system. The indirectness of relations between IT's first order impacts to business performance grow when the hierarchies and the length of cause-and-effect structures grow (Melville et al. 2004). The indirectness is related to the attributability and accountability issues (e.g. Marthandan and Tang, 2010) when trying to isolate IT's contributions for the higher level business measures.

Table 1: Challenges in IT business value evaluation.

| Challenges | Concepts and keywords | References |
|---|---|---|
| Focus of IT | - Strategic, transformational, informational or transactional<br>- Focus types e.g. operations or market focus<br>- Savings vs. added value | Mirani & Lederer (1998), Giaglis et al. (1999), Dedrick et al. (2003), Gregor et al. (2006), Tallon et al. (2007) |
| Nature of business system | - Socio-technical system<br>- Organisational structures and layers<br>- Tasks & Processes, Business processes<br>- Multilevel perspectives | Hamilton & Chervany (1981), Barua et al. (1995), Wegen & Hoog (1996), Palvia et al. (2001), Marthandan & Tang (2010) |
| Volume of IT impacts | - Broad impacts<br>- Multiple benefits & costs | Simmons (1996), Mirani & Lederer (1998), Kanungo et al. (1999), Irani et al. (2006) |
| Complementarity | - Contextual interaction<br>- Conversion contingencies, complementary assets<br>- Complementary organisational resources & capital | Davern & Kauffman (2000), Lee (2001), Dedrick et al. (2003), Melville et al. (2004) |
| Traceability for causes and effects | - Indirectness<br>- Attributability, accountability<br>- Locus of value vs. locus of analysis | Giaglis et al. (1999), Delone & McLean (2003), Melville et al. (2004), Petter et al. (2008), Davern & Wilkin (2010), Marthandan & Tang (2010) |
| Time & dynamics | - Payback delays<br>- Evolving effects, dynamic objectives<br>- Locus of impact vs. measuring delays<br>- Potential vs. realised benefits | Hamilton & Chervany (1981), Giaglis et al. (1999), Chan (2000), Peppard et al. (2007), Davern & Wilkin (2010) |
| Observability & measurability | - Intangibility, soft benefits<br>- Non-monetary, non-quantifiable<br>- Asset type, IT capital<br>- Hidden benefits & costs<br>- Perceived vs. independently observable | Giaglis et al. (1999), Ryan & Harrison (2000), Irani et al. (2006), Gunasekaran et al. (2006), Bajaj et al. (2008), Davern & Wilkin (2010) |
| Accountability for business impacts | - Economic, financial or accounting measures<br>- Black box | Simmons (1996), Martinsons et al. (1999), Bajaj et al. (2008), Davern & Wilkin (2010), Marthandan & Tang (2010) |
| Maturity of methods & theories | - Generic applicability vs. effective guidance<br>- Need for integrative or holistic approach<br>- Insufficient theoretical frameworks | Giaglis et al. (1999), Gunasekaran et al. (2006), Stockdale & Standing (2006) |
| Maturity of practices | - Benefits overstated<br>- Ambiguous goals & measures<br>- Focus on easy measures<br>- Unavailability of data for ex ante – ex post comparison | Hamilton & Chervany (1981), Ragowsky et al. (1996), Wegen & Hoog (1996), Peppard et al. (2007) |

**Traceability for causes and effects**

The volume of impacts together with complementarity complicate the traceability of IT impacts within the business system. The indirectness of relations between IT's first order impacts to business performance grow when the hierarchies and the length of cause-and-effect structures grow (Melville et al. 2004). The indirectness is related to the attributability and accountability issues (e.g. Marthandan and Tang, 2010) when trying to isolate IT's contributions for the higher level business measures.

**Time & dynamics**

In many cases, IT benefit realisation is delayed from the cost realisation (Peppard et al. 2007). Locus of value is dispersed into multiple levels of the organisation and there are delays between the value realisation and the evaluation of realised value. Additionally, IT impacts are not static: IT itself is upgraded and improved while the complementary factors and the context around the IT evolve (Chan, 2000). The goals for IT also evolve (Hamilton and Chervany, 1981). Time delays together with dynamic changes bring dynamic complexity into the business system.

**Observability & measurability**

The above mentioned socio-technical system characteristics, complementarity, and delay issues bring concrete challenges to the quantification and measuring of IT impacts.

Part of the benefits and costs are easily omitted from the explicit evaluation because those are structurally or temporally too far from the first order IT impacts. Additionally, some of the IT impacts are so intangible or 'soft' that they are not easily quantified into a measurable form.

**Accountability for business impacts**

The previously mentioned evaluation challenges explain why single economic measures are easily too narrow for covering the value of IT. Attributability and measurability issues affect the reliability of the financial measures for giving holistic credit for IT's contributions.

**Maturity of theories, methods & practices**

Many authors recognise that the underlying theoretical basis for IT value evaluation is scattered. Holistic and integrative evaluation approach is requested in order to tackle the complexity and multidimensional issues (e.g. Giaglis et al. 1999; Gunasekaran et al. 2006). However, one of the challenges is to find the proper balance of wide applicability and practical usefulness with specific situations (Stockdale and Standing, 2006). This balancing challenge motivates our study by setting scalability requirements for the investigated systemic approach.

Many of the evaluation challenges are rooted in maturity issues of organisational practices and evaluation culture. Examples include practices for collecting evaluation baseline data, defining explicit goals for IT or managing the evolution of measures and evaluation frameworks (e.g. Ragowsky et al. 1996; Wegen and Hoog, 1996).

## 3.3 Approaches for IT Evaluation

In the next paragraphs we present an overview of the categorised evaluation approaches, starting from general principles and advancing towards practical solutions.

**Principles for measuring & evaluation**

Due to the multidimensionality of IT impacts, benefits and costs, many studies advice for using multiple units of analysis. Measurements should integrate the results from several organisational levels, and they should utilise both qualitative and quantitative measures, or perceived and independently observable measures (e.g. Davern and Wilkin, 2010). Evaluation should be seen as an incremental and evolving practice (Giaglis et al. 1999; Chan, 2000), and it should be executed both before and after the investment decisions (Davern and Kauffman, 2000).

**Benefits & costs classifications**

The studies in this category identify and group common benefit and cost factors of IT. Simmons (1996) classifies benefits into five types: increased efficiency, increased effectiveness, added value, marketable product and development of corporate IT infrastructure. Gregor et al. (2006) classifies benefit types into transactional, informational, strategic and transformational benefits. Irani et al. (2006) introduce extensive cost taxonomy while Ryan and Harrison (2000) focus on social subsystem benefits and costs. These studies can be used as a reference or checklists when identifying relevant elements for business system modelling and further evaluation.

**Constructs for success or effectiveness**

Success or effectiveness constructs propose a structure for the factors impacting or leading towards desired goals. Information System Success Model by DeLone and McLean (2003) is a widely studied cause-and-effect structure that links IS quality, usage and satisfied users with organisational net benefits. Technology Acceptance Model (TAM, TAM2) elaborate IT impacts and usage at the individual user's level of analysis (Davis, 1989; Venkatesh and Davis, 2000). Other examples of IT effectiveness or impact constructs are provided by Grover et al. (1996), Kanungo et al. (1999) and Gable et al. (2008).

Instead of providing specific checklists for IT benefits or costs, the constructs in this category aim to understand the overall role and connections of IT within the socio-technical business system. As generic reference models, they give guidance for modelling systemic structures and interdependencies. Studies in this category can also identify complementary factors to be included in system models (e.g. Larsen, 2003).

**Constructs for evaluation process**

The studies in this category view the evaluation process or the framework as a unit of analysis. Hamilton & Chervany (1991) recognises two types of evaluation perspectives: 1) *goal-driven view* focuses on whether actions produced proper outcomes and the emphasis is on the results, and 2) *system-resource view* focuses on whether things were executed properly and the emphasis is on the process and the means. From the systemic evaluation point of view, both the above mentioned perspectives should be used when applying means-end thinking to identify the cause-and-effect structures.

Stockdale & Standing (2006) introduce Context, Content, Process (CCP) evaluation framework that takes a holistic view by asking *what* is evaluated

(Content), *why* evaluation is conducted and *who* affects the evaluation (Context) and *when* and *how* the evaluation is to be performed (Process).

Benefits Dependency Network (BDN) by Peppard et al. (2007) links the organisational change and business goals by using the means-ways-ends approach. Means cover the IT enablers and enabling changes which facilitate the ways level for improving, chancing or giving up something. Ways-level – the changes – target for business level benefits in order to satisfy the IT investment goals – the ends level. BDN is an example of a goal-driven approach that helps in understanding the business system through cause-and-effect structures. BDN is presented as a one-way hierarchy from means towards higher level ends, thus omitting explicit feedback mechanisms from the higher level issues back to the lower levels.

**Specific evaluation frameworks/methods**

Balanced Score Card based approaches are proposed for integrative and holistic performance and evaluation tools for IT/IS (e.g. Martinsons et al. 1999; Bajaj et al. 2008). BSC frameworks provide a familiar measuring concept for business managers but by default their hierarchical format do not support feedback structures from the higher level elements back to the lower level elements.

Tiernan and Peppard (2004) emphasize a lifecycle view to the IT benefits management - from vision to value realisation - and introduce a mathematical formulation for the vision-to-value vector.

System dynamics (SD) is used by several authors to evaluate IT/IS, for example Santos et al. (2008) combine SD with Multicriteria Decision Analysis (MCDA) within continuous performance management process, and Mutschler and Reichert (2008) introduce SD modelling based EcoPOST cost analysis framework for process-aware information systems. Pfahl & Lebsanft (1999) introduce a SD based integrated measurement, modelling and simulation (IMMoS) approach in a software development domain. One of the learnings from IMMoS trial project is the importance of a goal-driven top-down approach for scoping and maintaining the focus for system modelling and measuring efforts.

# 4 TOWARDS SYSTEMIC EVALUATION

The answer for our research question "*How to conceptualise the evaluation of IT business value?*" covered evaluation challenges and solutions from the IT/IS evaluation literature. The IT business value evaluation appeared to be a combination of complexity regarding the multidimensional value concept itself and the evaluation challenges with the multilevel IT impacts in the business environment. Several sources suggest an integrative and holistic evaluation approach that would cover multiple units of analysis, would combine tangible and intangible factors, recognise complementary factors, would be goal oriented and span the lifecycle of IT business case.

The above mentioned characteristics set the ground for a systemic evaluation approach. We propose a scheme of three tightly coupled building blocks for structuring further research on systemic evaluation: conceptual basis, methods basis and workflow basis.

## 4.1 Conceptual Basis

The conceptual basis covers the focal concepts of IT business value evaluation within a business system. At first, the concepts of *goal*, *benefit*, *cost* (or sacrifice), *IT impact* and *value* has to be semantically linked together. *A business model* and *an earning logic* are practical concepts that can be used to set the goals and valuing perspectives for IT impacts. *A (business) process* and *a service* are examples of concepts used to understand the execution logic and interconnections of a business system. In order to support the lifecycle view of IT, a *potential value* and a *realised value* should be linked with expected and realised benefits and costs.

The further research of the conceptual basis could produce a metamodel for guiding the population of case specific system models. While populating generic metamodels and identifying case specific system elements and their relationships, existing IT/IS literature provides rich examples as summarised in 'Benefits & Costs classification' and 'Constructs for success or effectiveness' sections.

## 4.2 Methods Basis

The methods basis gathers means for visualizing and modeling the linkage of IT impacts with benefits, costs and even with commensurable value units. Our further research relies on systems thinking and system dynamics. Systems thinking provides principles for defining system boundaries, understanding emergent properties and synergism of the business system elements. System dynamics (SD) is a set of methods for modelling the system structures and the dynamic behavior of the system over time (e.g. Sterman, 2000). SD is scalable from the *qualitative analysis* with causal loop diagrams to *quantitative analysis* with stock-and-flow diagrams and mathematical equations.

Qualitative SD provides potential means for the traceability and feedback analysis of IT impacts by applying cause-and-effect linking with balancing and reinforcing feedback loops. Qualitative modelling reveals the mechanisms behind the system delays and non-linear behaviour. Quantitative analysis gives further insights into the system beviour over time. Simulations can be used to test various system configurations, to find leverage points in the system structure, or to perform sensitivity analysis for the system variables (Sterman, 2000).

System dynamics methods are used as a ‘glue’ for integrating and modelling the conceptual basis elements and their interdependencies within the business system. The actual challenges of for example defining quantitative measures for intangible benefits and costs still remain. However, the recognition of the elements and relations affecting the value creation is the first step in ensuring that those factors are not left on their own but actively monitored and managed during the lifecycle of IT.

### 4.3 Workflow Basis

The workflow basis focuses on practical means of applying systemic evaluation methods and concepts in a real organisational context. The workflow practices should facilitate a seamless integration of the evaluation process and the business system organisation. How to obtain the required data from the stakeholders, how to scope and iterate the modelling, how to extract measures from the models are all example questions for further empirical studies.

## 5 CONCLUSIONS

This paper highlights the focal characteristics of the IT business value evaluation and proposes systems thinking and system dynamics as the core of a systemic evaluation approach. The systemic approach facilitates integrative perspective into the IT role within the business system: IT investments and the usage are seen as a continuous business case.

The further research on systemic evaluation approach is structured into conceptual, methods and workflow views. These views are currently utilised as the authors continue data collection and analysis of the lessons learned from the six industrial cases experimenting with systemic evaluation approach.

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# Analysis of IT-Business Models

## *Towards Theory Development of Business Model Transformation and Monitoring*

Christina Di Valentin, Dirk Werth and Peter Loos
*German Research Center for Artificial Intelligence (DFKI), Stuhlsatzenhausweg 3, Saarbrücken, Germany*
*{christina.di_valentin, dirk.werth, peter.loos}@dfki.de*

Keywords: Business Models, Performance Management, Business Processes, IT-Industry, Business Model Transformation.

Abstract: Companies in fast evolving industries like the IT-industry are continuously confronted with external influences on their business model. For these companies, it is crucial to be able to react rapidly on external and internal influences on their business model to prevail over competitors in the long term. So far, business model research mainly focused on static concepts like taxonomies, ontologies or components, not taking into consideration the dynamic relationships between the strategic business model layer and the layer of business processes. This paper presents the conceptual development and the implementation of a top-down and a bottom-up approach in terms of business modelling. The top-down approach describes the influence that IT-business models have on their underlying value creating activities on process layer, whereas the bottom-up approach shows how value creating activities in the IT-industry can be used as feedback indicator for the quality of the current business model. The goal of the presented research is to come one step closer towards a holistic theory development in the field of dynamic business model research by focusing on the interrelations between business model layer and the layer of business processes.

## 1 INTRODUCTION

Fast changing business environments like the IT-industry often force companies to continuously rethink and renew their current business model (Chesbrough 2007). Particularly for companies in the IT-industry, it can have drastic consequences when decisions about required changes on their current business model are made too late. The right business model is crucial to establish successfully in the marketplace as factors like changing customer preferences, new business partners, new technologies as well as new regulations continuously influence a company's business model (Cavalcante et al. 2011). A breakthrough about how a business carries out its operations can come along with an innovation of its whole business model (McGrath 2010). Thus, decision makers must be continuously aware about the threats to their company's business model in order to be able to react in time (McGrath 2010).

A business model provides an abstract view on a company's organizational structure as well as on its value creating activities (Al-Debei and Avison 2010; Demil and Lecocq 2010). It is commonly viewed as a mediator between strategy and business processes, which reflects in different granularity levels of the concepts from operational to tactical and to strategic level (Al-Debei et al. 2008). One way to overcome the challenge of rethinking and renewing a business model is to continuously monitor business processes in operations and to adjust the business model according to changes on process layer (Bonakdar et al. 2013; Bouwman et al. 2012). An analysis of the current business model helps companies to understand why certain firms can establish successfully on the market while the competitiveness of other companies declines (McGrath 2010).

Although, business models have already been discussed in many different ways (Markides 2006; Teece 2010; Zott et al. 2011), the focus so far has been mainly on static aspects like business model components (Afuah and Tucci 2004; Hamel 2002; Mahadevan 2000; Osterwalder and Pigneur 2004; Petrovic et al. 2001) or taxonomies (Mahadevan 2000; Tapscott et al. 2000; Timmers 1998), not taking into consideration dynamic aspects.

This paper focuses on the development of a holistic concept that depicts the transformation from IT-business models into business processes (top-down) as well as the feedback loop from business processes back to the business model (bottom-up). The software industry business model framework by

Schief and Buxmann (2012) forms the basis for representing aspects related to business model layer whereas process related characteristics of the IT-industry are depicted by means of the software industry value chain of Pussep et al. (2012). The research questions we address in this paper are:

*R1: "How can the existing relationships between the layer of business models and business processes be transferred into a theoretical construct?"*

*R2: "How can IT-Business Models be improved by means of an information system that provides recommendations for business model adaptation based on its underlying business processes?"*

We used both concepts to describe the influence IT-business models have on value crating activities on process layer and vice versa by carrying out a mapping of both concepts and integrating relevant key measures to monitor business processes and their corresponding business model elements. As a business model connects strategic layer and the layer of business processes (Al-Debei and Avison 2010), several stakeholders such as strategic decision makers, business developers, company founders and controllers of companies in the IT-industry benefit from the developed concept and its implementation.

The research method follows a design science-oriented approach. According to the design science methodology an artifact is being created within a prototypical approach in order to meet collected requirements fitting to a specific problem description (Hevner et al. 2004). The presented research is based on several artifacts. The basis for depicting the business model layer is represented by the software industry business model framework of Schief and Buxmann (2012). The software industry value chain with its value creating activities for IT-firms is used on process layer (Pussep et al. 2012). Based on these artifacts we analyzed the relationship between the IT-business model elements and the elements of the software industry value chain.

The goal of the presented research is to provide a basis for theory development in the area of dynamic business model research by depicting the relationship between process layer and business model layer in form of a reference framework. The presented work builds upon previously carried out research in the field of IT-business models regarding the top-down approach from business model transformation into business processes (Burkhart et al. 2012).

# 2 RELATED WORK

## 2.1 Term Definitions

The concept of business models is often described as closely related to the concept of strategy (Magretta 2002; Morris et al. 2005). In contrast to business models, business strategies specifically deal with competitive struggle by revealing possibilities to outperform competitors, while business models describe the collaboration of all participating business resources (Magretta 2002; Porter 1996). For this reason, business models are often described as a way of implementing a company's strategy (Bouwman et al. 2012). Osterwalder, Pigneur and Tucci (2005) describe business models as a '…conceptual tool containing a set of objects, concepts and their relationships with the objective to express the business logic of a specific firm'. Hence, business models provide a view on a company's logic of value creation (Al-Debei and Avison 2010; Demil and Lecocq 2010), whereas business processes describe the implementation of a concrete scenario into executable process steps (Hammer and Champy 1994; Scheer 1994). Thus, business processes describe which input factors are needed to produce a certain output (Hammer and Champy 1994). Misleadingly, in literature and practice the terms *business model* and *business process* are often used interchangeably (Magretta 2002).

The design of business processes usually begins with the determination of a company's business model and its strategic goals (Harmon 2009). Hence, a clear understanding about the scenario to be realized on process level can be achieved, as changes on a business model have an influence on the underlying business processes (Al-Debei and Avison 2010). This relationship can be also described inversely from process level back to the business model: The consideration of all relevant factors that are involved in the activities of business processes can be used on business model layer as analysis unit during the phase of planning business models. Thus, meaningful information for the design of business models can be obtained from process layer. Particularly business processes in the IT-domain are mainly ICT-enabled (Buxmann et al. 2012; Pussep et al. 2011). Hence, the successful implementation of a business model is largely dependent on the ability of an organization to successfully match their business processes to their supporting IT (Petrovic et al. 2001).

## 2.2 Business Modeling and Performance Measurement in the IT-Industry

Daas, Hurkmanns, Overbeek and Bouwman (2012) present a tool that supports the evaluation of alternative business models by incorporating market analysis data. Furthermore the tool weights the implications of business models on the partners of a company's value network. *$e^3$ value editor* (Gordijn and Akkermans 2006) allows business model designers to capture and evaluate business models from a financial point of view. *Business Model Tool Box* offers methods for designing business models. It is based on Osterwalder's (2010) 'Business Model Canvas' and supports the configuration of business models according to nine predefined building blocks (Osterwalder and Pigneur 2010; Osterwalder 2015). However, the tool only supports business model configuration not taking into consideration dynamic aspects related to business processes. The *EA Performance Reference Model of the Federal Enterprise Architecture* enables companies to link their strategy and their goals to the underlying process-KPIs. However, the focus of this framework is on aspects about modeling and strategic alignment. A positioning of companies within a certain industry branch according to their maturity of performance measurement and resulting implications on strategy and on business model level is not offered by this reference model (Camarinha-Matos and Afsarmanesh 2008). *CMMI (Capability Maturity Model Integration)* consists of five levels of process maturity (Staples et al. 2007). Beginning from process level, specific process KPIs like for instance 'ability to remove defects', 'costs of defect removal' or 'process capability & maturity' are assigned. These KPIs support assessing the quality of the software development process and the resulting software product. However, there is no link between process layer and the strategic aspects of the running business such as e.g. the needs of a software company's customers (Staples et al. 2007).

## 2.3 Requirements Derivation

The state of the art analysis shows that, so far, there neither exist a holistic methodology nor a tool that supports all phases from business model configuration, its transformation into business processes (top-down) as well as the way back from business processes to the business model (bottom-up). Based on the results of the state of the art analysis we derived the following requirements:

*Req. 1*: IT-firms must be able to describe their business model in a standardized manner. To simplify the process of business model configuration, companies must be able to choose from predefined building blocks the business model elements that are most relevant for their company.

*Req. 2*: IT-firms must be able to transform their business model into executable business processes (top-down). *Req. 2.1:* Therefore, an interface to business process layer has to be provided. *Req. 2*.2: In order to provide a mapping to process layer, industry-specific business processes have to be considered.

*Req. 3*: IT-firms must have the possibility to continuously monitor their business model in form of a feedback loop from process layer back to the business model (bottom-up). *Req. 3.1*: In doing so, process related KPIs must be defined that take into consideration the characteristics of business models in the IT industry. *Req. 3*.2: A standardized control dashboard should offer a permanent overview of the current business model. Whenever the company reaches critical thresholds the right contact persons have to be informed through the dashboard.

# 3 TOP-DOWN AND BOTTOM-UP BUSINESS MODEL CONCEPTS

## 3.1 IT-Business Model Framework

The software industry business model framework of Schief and Buxmann (2012) forms an important basis for the developed and implemented top-down and bottom-up concepts. It covers generic aspects about business models as well as economic principles that are characteristic for the software industry (Req. 1) (Kontio et al. 2005; Schief and Buxmann 2012; Rajala 2012). The constitutive elements of business models in the software industry have been derived through an identification of the most prevalent classes of software business models (Kontio et al. 2005; Popp 2011; Schief and Buxmann 2012). Moreover, performance implications are considered in the framework (Rajala and Westerlund 2012; Schief and Pussep 2013; Schief et al. 2012). The concept consists of 25 business model elements that are classified into the five categories *Strategy, Revenue Model, Product Manufacturing, Product Distribution* and *Usage*. Each business model element can be described according to several characteristics. The business model element *Investment Horizon* for instance can be described according to the characteristics

*Subsidence Model, Income Model, Growth Model, etc.* (Schief and Buxmann 2012).

## 3.2 Business Model Transformation into Business Processes (Top-down)

Each business model has an impact on business process layer in terms of required resources, process steps and involved organizational units like e.g. employees (Al-Debei and Avison 2010). During a company's start-up phase when companies create their business model, they often do not adequately consider the business processes that are triggered by the business model (Al-Debei and Avison 2010). However, with an increasing size of the company the consideration of the underlying business processes and their impact on business models becomes increasingly important. Therefore, we apply the indication of KPIs for specific business model elements and correlated process steps to measure the effects of business model transformation into business processes as well as to carry out adaptations on a business model. To establish a relationship between business model elements and operative business processes it is important to integrate BPM-tools. Business processes (Req. 2.2) are represented by the software industry value chain of Pussep et al. (2011, 2012) consisting of ten value chain activities. To each of these activities several specific business processes are assigned to (Pussep et al. 2012). We developed a connection between the derived business model elements and the business processes that are assigned to the activities of the software industry value chain by means of the ARIS methodology (Scheer 2002) through Event Driven Process Chains (EPCs). EPCs are flowcharts that can be applied in terms of depicting a company's business processes (Scheer 1994). An interface to the ARIS database enables to carry out this connection from business model to business process layer (Req.2.1). The ARIS method describes business processes according to four views: The *Organizational View* describes the organizational structure that is needed to carry out specific process steps. Concepts within the organizational view are depicted as organizational units. The *Implementation View* focuses on the performing aspect of a business process, i.e. its execution. The *Performance and Information Views* contain the required and produced resources within a process (e.g. intermediate products like software code or project plans) as well as the actions of process execution (e.g. a software product as output of the software development process or billing of the developed software product). Each of the 25 business model elements adheres the requirements for the transformation from business model into business process. Depending on the selected characteristics of each business model element, several business processes with different resources are triggered. Details, about how the top-down concept has been implemented can be found in Burkhart et al. (2012). If, for instance, a company decides to distribute its products not only on national level but also on international level, this change on the business model will have an impact on the corresponding value chain activities and its assigned business processes. Hence, the tool provides anytime an overview about how business processes are affected by the business model.

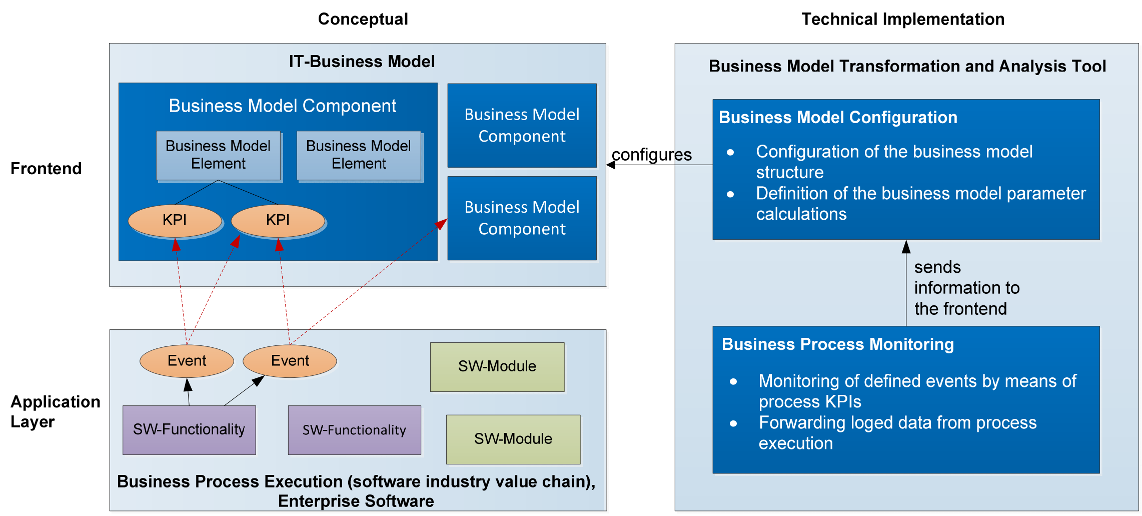


Figure 1: Bottom-up Concept: Feedback loop from process layer back to the business model (bottom-up).

### 3.3 Business Model Monitoring and Adaptation (Bottom-up)

In a next step, a methodology has been developed, which enables to measure a business model's quality based on its underlying business processes to which we also refer as *feedback loop from business processes back to the business model*. The goal of this method is to be able to continuously monitoring the quality of an IT-business model and to carry out real-time adaptations in order to improve the business model's performance. Figure 1 shows how the structural dependencies between a company's business model and its underlying enterprise software on process layer are considered in our bottom-up concept. The software industry value chain with its EPCs is classified to the application layer. Here, software modules, functionalities of the EPC as well as events can be mapped with KPIs to the corresponding business model elements. Therefore, users can select for each step of a certain business process relevant KPIs which will be mapped to the corresponding business model elements. The process KPIs have been derived in form of expert interviews with representatives from the software industry in order to identify the most relevant KPIs for each activity of the software industry value chain Bonakdar et al. (2013). We integrated the derived KPIs in our tool in form of a dropdown menu. By this means, users are free to select the most relevant KPIs for their company, such as 'cycle time', 'implementation time', etc., (Req. 3.1). After selection and import of the KPIs in the *Business Process Monitoring Component*, the current values of the KPIs are continuously monitored and sent to the business model. As soon as a certain threshold is passed, the tool sends this information from business process execution layer to the *Business Model Configuration Component*, where this is information is displayed in form of a control dashboard (Req.3.2).

The concept has been evaluated in form of expert interviews with decision makers in the IT industry. Regarding the concept of business model transformation, 9 of the interviewed companies stated that there still exists neither a concept nor an implementation of a company-wide mechanism which allows companies to estimate the impact of strategic decisions on process layer. Thus, all of the surveyed companies confirmed that it would be a benefit to have a tool, which is tailored to the processes and business model of their company in order to support to transform strategic aspects into executable business processes. Furthermore, the interviews have shown, that most of the surveyed companies do not use a company-wide performance measurement system in order to carry out internal or external benchmarking. Most of the interviewed IT-companies were not able to assign relevant key measures to specific activities of the introduced software industry value chain, but most companies are still in the process of identifying the most relevant KPIs for their companies. In most cases, KPIs are not yet related to the specific value creating aspects of the surveyed companies, they rather have a generic character. Hence, most of the companies stated that particularly our proposed bottom-up concept would provide a benefit in terms of linking performance measurement to the strategic aspects of their business model as many of the interviewees stated that they have significant problems in connecting their KPIs to specific elements of their business model

## 4 CONCLUSIONS

This paper presented a concept of business model transformation and analysis with a focus on IT-firms. Motivated by the lack of research regarding the interdependencies between business models and business processes we derived a top-down as well as a bottom-up concept to describe the relationship between IT-Business Models and value chains in the IT industry. The top-down concept describes how strategic decisions in business models can be operationalized and transferred into business processes whereas the bottom-up concept describes how information from business processes in form of KPIs can be automatically considered on business model layer to be able to monitor the quality of the business model. In future business model research, the developed top-down and bottom-up concepts serve as a basis for theory development, particularly in terms of the analysis and development of an automated tool support for business model configuration, transformation and analysis.

So far, the focus of our research has been on the IT-industry. However, the developed top-down and bottom-up concepts serve as blueprint for other industries. In order to apply the developed concepts in other industries, business model components and value chain activities of the respective industry sector have to be developed in order to depict the influences between business model and business process layer.

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# Domain-Specific Language for Generating Administrative Process Applications

Antonio García-Domínguez, Ismael Jerez-Ibáñez and Inmaculada Medina-Bulo
*Department of Computer Science, University of Cadiz, Av. Universidad de Cádiz 10, Puerto Real, Spain*
*antonio.garciadominguez@uca.es, ismael.jerezibanez@alum.uca.es, inmaculada.medina@uca.es*

Keywords: Model-driven engineering, domain-specific languages, business modeling, code generation.

Abstract: Some organizations end up reimplementing the same class of business process over and over from scratch: an "administrative process", which consists of managing a structured document (usually a form) through several states and involving various roles in the organization. This results in wasted time that could be dedicated to better understanding the process or dealing with the fine details that are specific to the process. Existing virtual office solutions require specific training and infrastructure and may result in vendor lock-in. In this paper, we propose using a high-level domain-specific language to describe the administrative process and a separate code generator targeting a standard web framework. We have implemented the approach using Xtext, EGL and the Django web framework, and we illustrate it through a case study.

## 1 INTRODUCTION

In many organizations, there is a recurrent kind of business process which we call an "administrative process". These administrative processes involve managing a document with a certain structure and tracking it through different states. In each state, different parts of the document have to be viewable or editable by people with different roles in the organization. State transitions usually happen due to human decisions (possibly after a meeting, a review or some kind of negotiation), deadlines or a combination of both. The process usually concludes by reaching a "final" state (e.g. "accepted" or "rejected").

These processes are usually kept within a single organization and are not particularly complex by themselves, but their sheer number within some organizations can produce a high amount of repetitive work. Implementing each of these processes from scratch wastes precious time on writing and debugging the same basic features (form handling, state tracking, internal directory integration and so on) which should have been invested in obtaining a better understanding of the process desired by the users and fine tuning the process-specific business logic. In some cases, the developer tasked with implementing the process is not familiar with some of the best practices of the target technology, needing more time and producing less than ideal solutions.

Another problem is that even after the process is correctly implemented, the framework the implementation is based upon may become obsolete to the point of requiring a complete rewrite. This is compounded by the fact that since the processes may have needed urgent changes and tweaks, they may not be well-documented anymore and may require careful reverse engineering, which is time consuming and prone to mistakes. It would have been much better if most of the code had been produced from a process description: changing the target framework of several obsolete applications would only require writing a different code generator and adding some customizations.

Our organization has evaluated various generic "virtual office" solutions for implementing these administrative processes and having them run in a high-level process engine. While these solutions were acceptable for the simplest cases, adding process-specific UI and business logic and integrating them with in-house systems would have required learning yet another technology that may become obsolete or lose support in the long run. It would be much better if the resulting implementations were based upon a standard web framework chosen by IT, so it could be maintained by regular staff.

In this paper, we present the first version of a technology-agnostic domain-specific language dedicated to concisely describing these administrative processes. We show how it can describe an examination process and how we developed a code generator that followed the best practices of the Django web framework (Django Software Foundation, 2015) to implement the process as a website. The generated website is ready to be used and can be customized by any developer familiar with the Django framework.

## 2 RELATED WORK

There exist several business process management systems (BPMSs) that include some support for form-based steps within workflows, such as Bonita (Bonitasoft, 2015) or Intalio (Intalio, Inc., 2015). These engines are usually tightly integrated with a design tool which uses a graphical notation (usually BPMN-based) to describe the processes. This graphical notation is normally extended with engine-specific annotations to provide the full semantics of the process, and is persisted using XML-based formats.

While these systems can describe a much larger class of business processes than our DSL, the resulting process definitions are highly dependent on the underlying engine: migrating the same process to a new technology may require a rewrite. Version control is still possible with XML-based formats, but meaningful comparisons and merges require special-purpose tools. In addition, using a BPMS effectively requires a considerable amount of training, consulting and process analysis, which may not be feasible in smaller IT departments. Our approach focuses on a specific kind of business process (manage a complex document through multiple states, with different access rules in each state) and produces a standard web app that can be maintained as any other.

Scaling back from full-fledged BPMS engines, there have been many attempts to simplify the development of form-based applications. One recent initiative in this regard has been the EMF Forms (Eclipse Foundation, 2015b) Eclipse project. Using its tools, users can define the domain model and abstract layout once and then render it in various technologies, such as SWT or JavaFX for desktop apps or Tabris for mobile apps. On the one hand, EMF Forms allows developers to specify the concrete layout for the resulting forms, unlike our DSL, which delegates on the generator for the presentation aspects. However, a DSL could cover aspects that EMF Forms does not, such as access control and state transitions.

Another related topic is domain-driven design (DDD): an approach on software development that asserts that the primary focus in most software projects should be the creation of an adequate model that abstracts the problem domain, and the implementation of the relevant business logic around it (Evans, 2003). In this regard, several frameworks have been implemented to support DDD, enabling rapid iterations by generating a large portion of the application from a "pure" domain model (e.g. a set of Plain Old Java Objects or POJOs), such as Apache Isis (Apache Software Foundation, 2015) or OpenXava (OpenXava.org, 2015). In a way, a DSL conforms to the same view of producing software from a description of the problem domain: the only difference is that the DSL is focused on a specific kind of problem domain, rather than the generic approach of a DDD tool, making it more productive in that particular case.

In the context of e-government, several works have identified some differences in the way e-government processes should be modeled, in comparison to the business processes in the private sector. Klischewski and Lenk argued that in the public sector, many processes involve unstructured decision making (whether by a single official or after a meeting) and negotiations, so officials would need to be able to alter the course of the process (Klischewski and Lenk, 2002). Later in the same work, Klischenski and Lenk proposed a set of "Admin Points" as reusable process patterns that could be used as a shared vocabulary for e-government business processes. In a DSL, many of these admin points which involve negotiation and unstructured decision making could be modeled using decision-based transitions.

## 3 LANGUAGE DEFINITION

Summarizing the discussion in the previous sections, the design requirements for the language are:

- The description of a process should include the information to be stored within the managed document, the roles involved and the states that the document goes through.
- Each state should list the roles that can view or edit the different parts of the managed document.
- State transitions based on user decisions and dates should be supported by default, and custom business logic should be easy to integrate later on.

### 3.1 Abstract Syntax

Figure 1 shows a UML class diagram with the abstract syntax of our DSL. An APPLICATION is divided into ELEMENTS. There are five kinds of ELEMENTS. SITE is the simplest one: it only declares the name of the application (e.g. "Billing"). OPTIONS elements contain key/name pairs (PROPERTY instances) that may be useful to external generators.

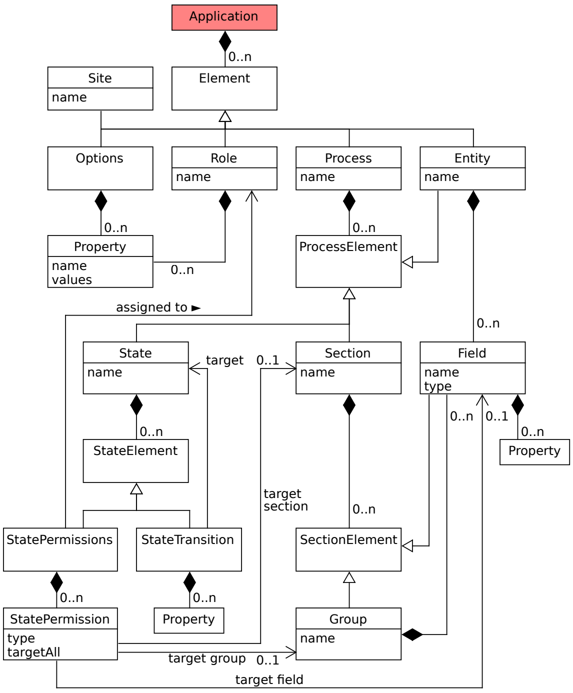


Figure 1: UML class diagram of the DSL's abstract syntax.

Next are ROLEs. These represent particular roles within the organization (such as "Accountant"). These elements provide a name and a set of PROPERTY instances which may be used by the generator to integrate the role with in-house user directories (such as an LDAP directory).

ENTITY elements represent data entities that must have been created before any documents can be filled in, such as "Country", "State" and so on. An ENTITY contains FIELD instances with the information to be stored about it. Every FIELD has a name and a domain-specific type (such as "currency" or "identity document") and zero or more PROPERTY instances providing additional information to generators.

Finally, the main and most complex kind of element is a PROCESS. These represent entire administrative processes (e.g. "Request for Leave"). They can contain three kinds of PROCESSELEMENTs:

- ENTITY instances, which will be specific to the process in this case. In the "Request for Leave" process, "LeaveReason" instances could be the various reasons for the leave.
- SECTION instances contain the FIELDs of the managed document, which can be optionally subdivided into GROUPs. A section could be "Billing information", and a group could be "bill item" (containing the "Price", "Quantity" and "Description" fields, for instance). This structure is useful for generating code and specifying access rules.

Listing 1: Simplified concrete syntax for our DSL.

```
site SiteName;
options { (Property;)* }
(role RoleName { (Property;)* } | role RoleName;)*
(entity EntityName {
  (Type ((Property (, Property)*))? Name;)*
})*

(process ProcessName {
  (entity EntityName {
    (Type ((Property (, Property)*))? Name;)*
  })*
  (section SectionName {
     (Type ((Property (, Property)*))? Name;
     | group GroupName {
       (Type ((Property (, Property)*))? Name;)+
     } )*
  })+
  (state StateName {
   (permissions RoleName {
      ((editable|viewable) all;
      | (editable|viewable) SectionName;
      | (editable|viewable) SectionName.GroupName;
      | (editable|viewable) SectionName.FieldName;
      | (editable|viewable)
         SectionName.GroupName.FieldName;
      )*
   })*
   (transition (Property (, Property)*) StateName;
)* })+ })*
```

- STATE instances represent the states that the managed document can be in. It can contain a set of STATEPERMISSIONS for each role of interest, which in turn contain STATEPERMISSION instances that describe the kinds of actions that are available to the role. A role can receive all permissions at once, or it can receive the ability to edit or view a single section, group or field.

  A STATE can also contain STATETRANSITIONs to other states. A transition can activate when all the conditions (specified using PROPERTY instances) are met: these conditions could combine explicit decisions by users ("Accepted" or "Rejected"), dates ("Past deadline") or custom business logic. Alternative paths to the same state can be modeled with several STATETRANSITIONs.

## 3.2 Concrete Syntax

Since editing and version control should not require any special-purpose tools, we have picked a textual notation for the DSL which is mostly a one-to-one mapping to the model entities.

Listing 1 shows a simplified version of our original EBNF grammar for the concrete syntax. As usual, `(x)+` means "one or more x", `(x)*` means "zero or more x", `(x)?` means "zero or one x" and `x|y` means "x or y". Whitespace is ignored. Literal `(` and `)` and keywords are shown in bold, to avoid confusion. A *Property* is of the form `Name = Value (, Value)*`.

As the grammar can fit into less than 40 lines after some simplifications, we can conclude that it is a rather simple DSL that should be easy to learn by the IT staff. However, it has a considerable number of cross-references in it, so it will require good tooling support to ensure that these references are not stale.

# 4 CASE STUDY

In this section, we will present a case study that uses the DSL to describe a simple examination process and then generate a web application that implements it. After outlining the process itself, we will describe the most important aspects of our implementation and evaluate the results obtained.

## 4.1 Description

The process in this case study is a test, involving two roles ("student" and "teacher") and these steps:

1. The student starts the test by introducing their personal information and answering the first part. Some of the questions are free-form, some have a predefined set of answers, and one of the questions pull answers from the database.

   The teacher can already see all the partially filled-in exams, but cannot enter any grades yet.

2. After a certain date, the second part of the test (with two numeric questions) becomes visible and the first part of the test is no longer editable by the student. Students can also fill in what they think about the test. Teachers can still see everything, but cannot enter any grades yet.

   The test can be turned in for examination before a certain deadline: after that deadline, it is turned in automatically and is no longer editable.

3. Once the test has been turned in, the teacher can grade it, but the student cannot see the grade yet.

4. After the teacher confirms the final grade, the examination is "closed" and the student can now see the grade. All fields are now read-only.

A simplified version of the DSL-based description of the process is shown in Listing 2. Some of the dates and field names have been shortened to save space.

Line 1 declares that the application to be generated has the name "School". Lines 2–5 include several options for the code generator that targets the Django web framework: in particular, they suggest using a certain base template that follows the organizational image, which is included in a Django app available at a certain URL. Line 6 declares the previously mentioned "student" and "teacher" roles.

Listing 2: DSL-based examination process.

```
1  site School;
2  options {
3    django_base_template = "template/base.html";
4    django_extra_apps = "template = https://.../";
5  }
6  role student; role teacher;
7
8  process exam {
9   entity Answers3 { string answer; }
10  section personal {
11   fullName studentname;
12   identityDocument(label="National ID:") nid;
13   email(label="Email") mail;
14  }
15  section test {
16   group part1 {
17    string(blank="True") q1;
18    choice(values="A1,A2,A3",blank="True") q2;
19    choice(table="Answers3",blank="True") q3;
20   }
21   group part2 {
22    currency(label="Q4 (euros):",blank="True") q4;
23    integer(label="Q5 (integer):",blank="True") q5;
24   }
25   choice(values="Good,OK,Bad",blank="True") opinion;
26  }
27  section evaluation { float grade; }
28
29  state initial {
30   transition(decision_by="student",
31    after_date="2015/03/01-14:00:00",
32    before_date="2015/03/07-14:00:00") part1;
33  }
34  state part1 {
35   permissions teacher { viewable all; }
36   permissions student { editable personal,
37                                  test.part1; }
38   transition(after_date="...") part2;
39  }
40  state part2 {
41   permissions teacher { viewable all; }
42   permissions student {
43    viewable test.part1;
44    editable personal, test.part2, test.opinion;
45   }
46   transition(decision_by="student",
47    before_date="...") evaluation;
48   transition(after_date="...") evaluation;
49  }
50  state evaluation {
51   permissions teacher { viewable all;
52                         editable evaluation; }
53   permissions student { viewable personal, test; }
54   transition(decision_by="teacher") closed;
55  }
56  state closed {
57   permissions teacher { viewable all; }
58   permissions student { viewable all; } }
59 }
```

The rest of the listing from line 8 onwards is dedicated to the "exam" process. An entity "Answers3" is declared at line 9: its instances are used for the answers for question 3. In lines 10–27, the fields of the document are organized into three sections. The "test" section is divided into two groups and one additional field: using groups simplifies access control specifications later on. The optional fields have "blank" set to "True".

Lines 29–58 describe the 5 different states the process can be in. The "initial" state is a special case: it represents the state before the process starts, and its transitions describe who can start the process and when. The other 4 states match the four stages of the

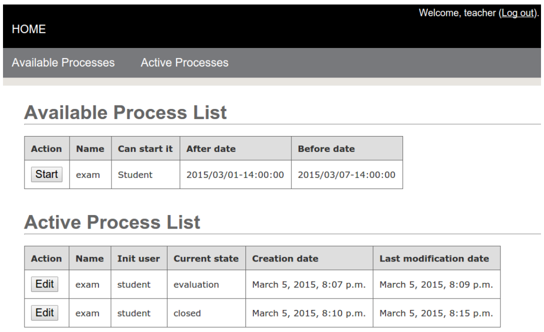


Figure 2: Generated web app: process list.

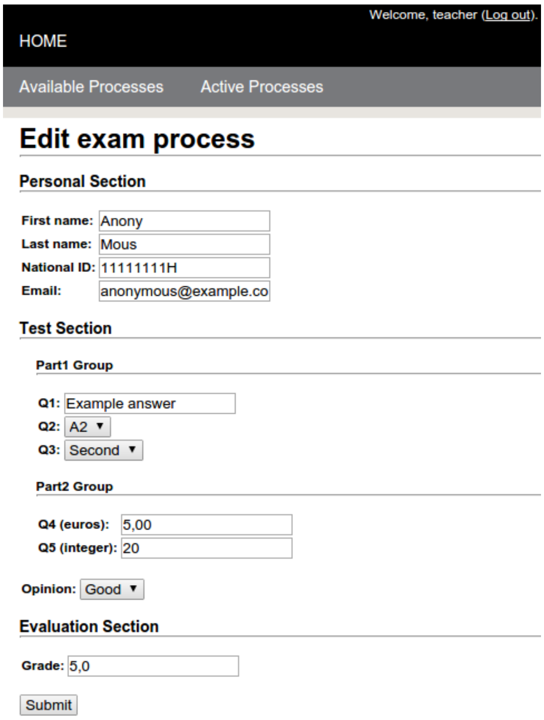


Figure 3: Generated web app: process form.

examination which were described before.

## 4.2 Implementation

The parser and editor for the language in Section 3 have been implemented using Xtext (Eclipse Foundation, 2014). From an EBNF grammar, Xtext generates a metamodel with the abstract syntax of the language and a set of Eclipse plugins which provide a parser and an advanced editor with live syntax checking and highlighting, autocompletion and an outline view.

We have also implemented a separate code generator that takes an APPLICATION described with our DSL and produces a web application in the Django framework. The generator is written in the Epsilon Generation Language (Eclipse Foundation, 2015a), which provides modularity and the ability to have "protected regions" that are preserved when overwriting an existing file. Our current version of the EGL source code for the Django generator has 3045 LOC.

The code generator produced from the example in Section 4.1 a ready-to-use Django site backed by a PostgreSQL relational database (shown in Figure 3). Thanks to the use of several advanced features in Django, the site only required around 1000 lines of Python code, 400 lines of HTML templates and 264 lines of documentation and support scripts.

## 4.3 Current Limitations

The DSL, its tooling and the evaluated generator currently present several limitations. One self-imposed limitation is that they do not aim to produce 100% of the required code: the generated code will always need to be customized in some way, due to special needs on the user interface, custom business logic that has to be added, or unexpected integrations with legacy systems. Following the accepted approach in the existing literature (Fowler, 2010), we have chosen to keep the DSL small and focused on describing administrative processes.

The DSL is focused on describing the current process, and does not have any provisions for migrating running processes to a new version with different states or very different information. Our current approach is to delegate on the target framework of the generator: for instance, since version 1.7 the Django framework has built-in data and schema migrations.

Since we transition to a new state as soon as its conditions are met and ignore all other transitions in the old state, we implicitly only allow one state to be active at a time. While this makes the DSL less general than a full-fledged business process modeling language such as BPMN (Object Management Group, 2014), largely based on Petri nets, it is on par with some of the "virtual office" platforms we evaluated and the legacy applications it is intended to replace.

States do not enforce preconditions, invariants or postconditions yet, beyond simply checking that the mandatory editable fields have been filled in. We intend to add support for the most common conditions to the DSL in the short term: the most advanced cases will be delegated to a protected region, which will have to be filled in by the developer.

## 5 CONCLUSIONS

A simpler class of business processes (administrative processes) are very common in many organizations today: these processes basically consist of managing a form through many states, involving various roles in the organization. Implementing the basic logic and infrastructure for them again and again wastes precious time that could be used on understanding better the process and implementing the fine details correctly.

This paper has presented an approach to improve the efficiency of implementing these solutions, while avoiding lock-in into a particular technology: using a high-level domain-specific language (DSL) for describing the process and writing a separate code generator for each target technology. The approach has been illustrated by describing an examination process, and has been implemented with Xtext (Eclipse Foundation, 2014) on the DSL side and EGL (Eclipse Foundation, 2015a) on the code generation side. The code generator produces a ready-to-use site that follows the best practices of the Django web framework (Django Software Foundation, 2015), accelerating the implementation of the process.

Our results have several limitations. The generated code is ready to be used, but will normally need to be customized to fully meet the needs of the users: we have preferred to keep the DSL and code generators small and focused. Additionally, the DSL is not intended to replace general-purpose workflow-based notations: it is specifically designed for the simpler administrative processes. Finally, we have only evaluated our approach through internal case studies.

We have several lines of work ahead. As we develop more advanced case studies, we will expand the DSL with concepts such as limits on number of processes per user or state pre/postconditions. In addition to refining the tooling, we will look into performing live validation of the structure of the process itself and providing graphical visualizations. We will also develop code generators for other web frameworks that are common in our organization (e.g. Symfony 2). Over the medium term, we will conduct studies with developers within and beyond our organization, evaluating the usability and productivity of our approach.

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# varBPM
## *A Product Line for Creating Business Process Model Variants*

Andreas Daniel Sinnhofer, Peter Pühringer and Christian Kreiner
*Institute for Technical Informatics, Graz University of Technology, Austria*
*{a.sinnhofer, christian.kreiner}@tugraz.at, p.puehringer@inode.at*

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Abstract: Business processes have proven to be essential for organisations to be highly flexible and competitive in today's market. To manage the life-cycle from modelling such business processes over the execution and the maintenance, Business Process Management Tools are used in the industry. In many cases, different business processes do only vary in few points. This leads to the situation that new business process variants are formed through copy or clone of previous solutions leading to a high number of instantiated process templates. However, this means that changes to a template affects many processes, where all of them need to be manually updated, which can lead to a considerable amount of work and money for a bigger company. In this paper, we will present a framework for the integration of business process modelling tools and software product line engineering tools to provide a systematic way to reuse and trace process variations of whole process families.

## 1 INTRODUCTION

Business Process (BP) oriented organisations are known to perform better regarding highly flexible demands of the market and fast production cycles (McCormack and Johnson (2000); Hammer and Champy (1993); Valena et al. (2013); Willaert et al. (2007)). These goals are achieved through the introduction of a management process, where business processes are modelled, analysed and optimised in iterative ways. Nowadays, the business process management is also coupled with a workflow management, providing the ability to integrate the responsible participants into the process and to monitor the correct execution of the business process in each process step. To administer the rising requirements, so called business process management tools are used (BPM-Tools) which cover process modelling, optimization and execution. In combination with an Enterprise-Resource-Planning (ERP) system, the data of the real process can be integrated into the management process.

In many cases, business processes do only vary in some points, which leads to the situation, that new process variants are created through a copy and clone of old solutions (often called as templates). As a result, such templates are instantiated in many various processes which makes the propagation of process improvements time and cost intensive for a bigger company. Also the consistency of the documentation of this huge number of process variants is a challenging task.

Software Product Line Engineering (SPLE) techniques have been successfully applied for almost any domain, providing a technique for the systematic reuse of domain artefacts. Although the topic of product line techniques in the domain of business process modelling is not new (e.g. Gimenes et al. (2008); Rosa et al. (2008); Fantinato et al. (2012); Derguech (2010)) only little work is found for the issues related to the correct configuration of whole process families (e.g. Hallerbach et al. (2009a,b)), the integration into existing toolchains and the reuse throughout various production plants. Thus, our approach is focused on developing a framework for the integration of a SPLE Tool and a BPM Tool, to provide a generic way to generate process variants of whole process families. In particular, we use the SPLE Tool for a systematically reuse of expert knowledge in form of valid process variations, designed in an appropriated BPM Tool. The integrity of the process variations is secured by the capabilities of the BPM Tool and a rich constraint checking in the SPLE Tool. Furthermore, our proposed approach enables the abilities to automatically trace all process variants for an automatic propagation of changes and process improvements and the systematic integration into the capabilities of the BPM Tools such as documentation generation, workflow engines, process optimisation tools, etc.

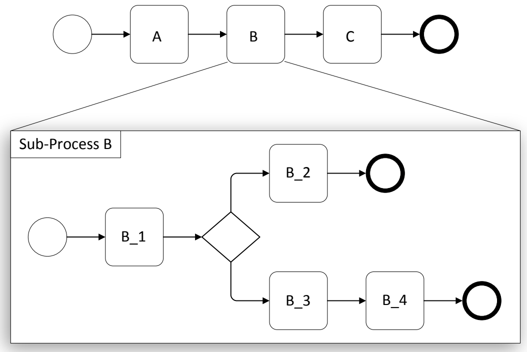


Figure 1: Principal structure of a business process according to Österle (1995) which is used for our approach. Starting with an abstract description of the process, the tasks are further described in sub-processes until a complete work description is reached (microsopic level).

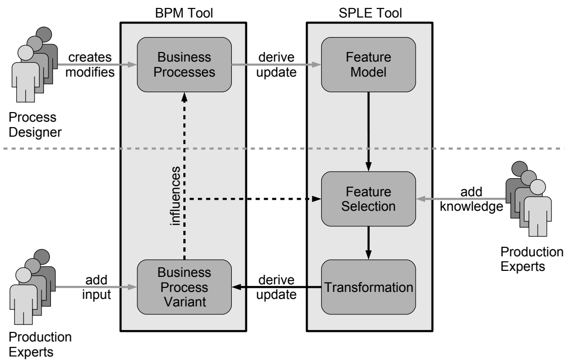


Figure 2: Overall conceptual design. The upper side of the Figure describes the domain engineering part and the lower side of the Figure the application engineering part.

This work is structured in the following way: Section 2 gives an overview over the concepts of tool integration and the design paradigm for business processes which is needed for our framework. Section 3 presents the conceptual design of the framework and states construction rules of the according feature models and some design rules for the BPM Tool. In section 4 we will introduce our case study regarding some metrics and implementation details. Section 5 summarizes the related work and finally section 6 concludes this work and gives an overview of open issues.

# 2 BACKGROUND

## 2.1 Tool Integration

According to the work of Karsai et al. (2005), two possible patterns exists for tool integration. The first approach is named ”Integration based on integrated models” and is based on the idea of a common data model which is shared between each participating tool. This means that each tool needs two model converters, one for the conversion of the native data model into the common data model and one for the opposite direction. The data is shared over a so called integrated model server where each tool can publish or consume data. For obvious reasons this approach is meaningful applicable if each participating tool has a similar data model. A drawback of this approach is that it does not scale very good with the number of connected tools.

The second pattern is named ”Integration based on process flows” and is based on the idea of a point to point message based communication. Each participating tool registers itself at a backplane providing information about what data is shared and what data is intended to be consumed. As a result, this approach scales better with the number of participants since potentially fewer model transformations are needed at which each model can be better optimized regarding the communicating tools. This approach is used in those situations, where the data is processed in a specific sequence.

For our framework both patterns would be possible. Due to the fact, that the number of participants is small (in most circumstances there is only one SPLE Tool and one BPM Tool) and since the representation of business processes is very similar throughout various tools, the first approach is more applicable.

## 2.2 Business Processes

A business process can be seen as a sequence of tasks/sub-processes which needs to be executed in a specific way to produce a specific output which is of value to the costumer (Hammer and Champy (1993)). According to Österle (1995) the process design on the macroscopic level (high degree of abstraction) is split up into sub-processes until the microscopic level is reached. This level is reached, when all tasks are detailed enough, so that the process employees can use it as work instructions.

In other words, a complete business process is designed in layers, where the top layer is a highly abstracted description of the overall process, while the production steps are further refined on the lower levels. As a result, the lowest level is highly dependable on the concrete product and production environment, providing many details for the employees. In fact the top layers are – mostly – independent from the concrete plant and the supply chain and could be interchanged throughout the production plants, whereas the lower levels (the refinements) of the processes would need to be reconsidered. Figure 1 gives an overview of such a structure. Variability of such a process structure can either be expressed through a variable structure of a process/sub-process (e.g. adding/removing nodes in a sequence) or by replacing the process refinement with different processes. The current version of our developed prototype focuses on the second method but the framework is not limited to it.

### 2.3 Informal: Feature Model

A feature is defined by Kang et al. (1990) as a *"prominent or distinctive user-visible aspect, quality, or characteristic of a software system or system"*. In context of a Software Product Line, a feature model is a model which defines all these features and explicitly states their relationships, dependencies and additional restrictions between each other. It enables the ability to visually represent the variable parts of a system and the options available for all products of a product line.

## 3 VARIABILITY FRAMEWORK

### 3.1 Conceptual Design

The overall conceptual design is based on a feature oriented domain modelling approach and is displayed in Figure 2. It is intended, that the domain experts (process designer) design process templates in the according BPM Tool, providing also all needed information for e.g. a workflow engine. Based on these templates and the abstract process model (the top level description of the process) a feature model is partially automatically created/updated with the guidance of the domain experts. This is done by identification of the variation points and the linkage of the according variations on every process level. Each variation can contain additional variability by either defining new variation points where further refinement can be linked to or by a variable process structure. Additional constraints regarding the possible combination of features are intended to be modelled in the SPLE Tool, but are not limited to it. In application engineering the domain experts (not necessarily a process designer, but someone who knows the current needs of the production) adds his knowledge and selects the needed features. The found description is then automatically transformed in a real business process which can be executed by the workers. During

Table 1: Needed process information within the SPLE Tool.

| property name | description |
|---|---|
| id | A unique id to identify the process/task |
| category id | A unique id of the category of the process |
| display name | A human readable and understandable name of the process/task |
| children | A list of ids which references the processes/tasks of the process itself (empty if the microscopic level is reached) |
| additional data | A list of additional data which is needed for the concrete instantiation of the process. E.g. data for a workflow engine, the responsible workers, etc. This data can be provided through the BPM Tool (almost static) or can be design variable in the SPLE Tool. |

the process execution, loads of data is generated regarding the performance and efficiency of the process. Thus, it is possible that some additional information is added to the derived processes which leads to a possible influence of the according business process templates or a possible influence of the feature selection. This flowback mechanism is an important task and needs to be considered for the maintenance and the evolution throughout the lifecycle of a process.

For illustration a short example for the flowback mechanism is given: Task B of the process displayed in Figure 1 could be dependent on the logistic chain of a supplier of a specific part or material. If during the execution of the process the supplier is changed, it is also likely that the overall control of the logistic chain is changed due to the fact that the newly integrated supplier can only deliver goods in a specific way. If the process of the logistic chain was not already modelled, then the process designer would need to create a new process variant and would need to update the existing feature models first. After this is done, our proposed toolchain needs to update the feature selection of the respective process in the SPLE Tool. This automatically updates the structure of the overall process variant, leading to an almost on the fly update of the complete process workflow especially when the process variation was already modelled.

Summarizing this concept means that the SPLE Tool is responsible for the following points: It needs to assist the domain experts (process designer) during

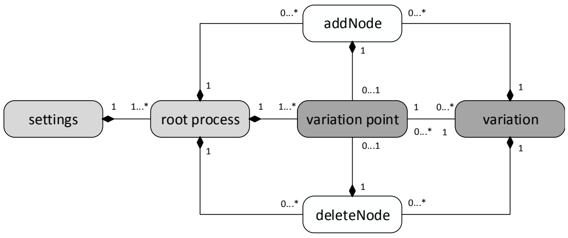


Figure 3: Feature model construction rules. The white parts cover the variability on the process level itself and the dark grey parts cover the variability between each layer of the overall process structure.

the (partially) generation of the feature models and during the selection and creation of the concrete product variant. Furthermore, it has to keep track of all generated process variants to automatically apply process template improvements or changes to the overall process structure and to flow back information added during the execution in the BPM Tool. To do so, the tool needs information about the properties of the process displayed in Table 1. The BPM Tool is responsible for the creation of semantically correct process variants and to provide capabilities which are of value for the developing company e.g. automatic documentation generation, workflow engine, etc. For obvious reasons, each Tool must have rich import/export capabilities or the ability to integrate user defined plug-ins to extend the functionality.

## 3.2 Type Model

To model the variability within the SPLE Tool in a structured way, the feature model should support the following type models:

- **settings**: Is a data model, containing information for the tool adaptors to identify the right datasets (e.g. identifier of the database of the BPM Tool from which the process structure is imported; login settings, etc.)
- **root process**: A process model of the top level process and therefore an abstract description of the overall process sequence. It consists of various nodes where some of them deal as variation points.
- **variation point**: A node in a process where at least one variation can be linked to.
- **variation**: A process model for a task or a subprocess which can be linked to a number of variation points. If it is a process, it can also contain variation points or a variable process structure (addition/deletion of nodes).
- **addNode**: Adds a node (task or process model) at a specific location of the process structure. This added node can also be a variation point for further refinements. The addition of the node can be dependent on the feature selection.
- **deleteNode**: Deletes a node (task or process model) at a specific location of the process structure. The deletion of the node can be dependent on the feature selection and hence it is also possible to link further refinements to this node.

The construction rules for this type model can be seen in Figure 3. The settings node is only instantiated once in such a model. The root process is somehow very similar to a variation, but with the difference that it must contain variation points (to prohibit a ”Blob” anti pattern [Brown et al. (1998)]).

## 3.3 Design Rules for Business Processes

Aforementioned, the processes should be designed as stated by Österle (1995). Secondly we have noticed, that almost every bigger BPM Tool supports the assignment of specific group identifiers to groups of processes, providing a more structural design of the processes. Thereby it is possible to automatically map specific groups of processes to a specific variation point. This leads to the situation that new variations can be automatically detected and can be advocated for an integration into existing feature models. Furthermore, the structuring in groups of processes enables the ability to introduce a constraint check so that variation points are limited to specific groups of processes. This increases the assurance in the creation of semantically valid processes.

# 4 INDUSTRIAL CASE STUDY: VARBPM

In this section an overview over our industrial case study is given, which describes the domain of our industry partner and the developed toolchain.

## 4.1 Industrial Project Partner

Our project partner Magna Cosma[1] is an international company in the metal stamping and assembly industry – specialised on class-A car body panels and closure parts (e.g. doors) – with several plants all over the globe. The implemented business processes

[1] http://www.magna.com/de/kompetenzen/karosserie-fahrwerksysteme

are mostly controlled by an SAP infrastructure and are designed with the BPM-Tool Aeneis[2]. Although some plants are specialised on the same production parts, almost every plant develops and maintains their own business processes, which makes it difficult to compare processes, mark bottlenecks, optimise the processes and publish the changes to other plants.

## 4.2 Tool Integration

As mentioned before, the tool integration of the SPLE Tool (pure::variants[3]) and the BPM Tool (Aeneis) is based on the Pattern "Integration based on Integrated Models". The integrated data model contains the relevant data enumerated in Table 1 where all fields are of type String respectively an array of Strings for the children and data field. This means that the native data model of the SPLE Tool is the integrated data model and hence only the BPM tool adaptors need to implement a data conversion. To support an update mechanism without sending the complete process, each published dataset can be assigned to a specific type indicating what should happen with this dataset. Possible types are:

- **New**: Indicating that this dataset was not published before and hence it should be integrated directly just as is.
- **Update**: Contains the id of the according dataset and the data which shall be updated. Non specified attributes are not affected.
- **Remove**: Contains the id of the according dataset which should be deleted out of the system. Linked variations of such a process are not affected.

The developed tool adapters are also applicable to get notified when data is added/updated so that such changes are processed almost immediately. If this mechanism is not supported by the participating tool connector, an operator needs to trigger this update mechanism manually. In the current development, the SPLE Tool needs to check manually for updated data since this task is intended to be supported by an domain expert, whereas the BPM Tool uses the benefits of the immediate notification system. The communication of the tools is done by an XML based file exchange and due to some consistency issues the communication is only possible if both tools are running. I.e. deriving process variants is only possible if the BPM Tool is running too.

[2]http://www.intellior.ag

[3]http://www.pure-systems.com

## 4.3 pure::variants

pure::variants is a feature oriented domain modelling tool and is based on Eclipse. As such, it can easily be extended based on java plug-in development. During the implementation of this project, five different plug-ins where developed:

- An import plug-in, which is capable of importing the process structure - including the definition of variation points and the according variations - and converting it into a feature model compliant to the construction rules displayed in Figure 3 without the white parts.
- An extension to the internal model compare engine so that different versions of created feature models can be compared with each other.
- An update mechanism to automatically search for deleted / added variations or updated process structures, providing graphical assistance for the domain expert.
- An extension to the internal model transformation engine so that the feature selection is automatically converted into a business process in the common data model; This process is then delivered to the attached BPM Tools, so that a native version of the process can be created/updated and executed.
- Additions to the internal model check engine to model and create only valid processes (e.g. checks related to the feature selection, the consistency of the feature model, etc.).

To keep track of all generated business process variants, a list including all ids of the processes is stored and maintained in a file located in the same directory as the variant description model (feature selection), but hidden from the user perspective. This list is automatically updated when a process variant is deleted in the BPM Tool or created with the SPLE Tool. pure::variants also provides a framework for the comparison of different models, which enables the ability to compare different process variants in an efficient way.

## 4.4 Studied Use Cases and Results

In the list below, use cases can be found which we investigated during the development of our approach regarding the performance of our toolchain (time saving). The according results are displayed in Figure 5, where the white bars are related to the manual case and the grey bars to our approach. Although the varBPM approach automatically integrated each derived process into the capabilities of the BPM Tool

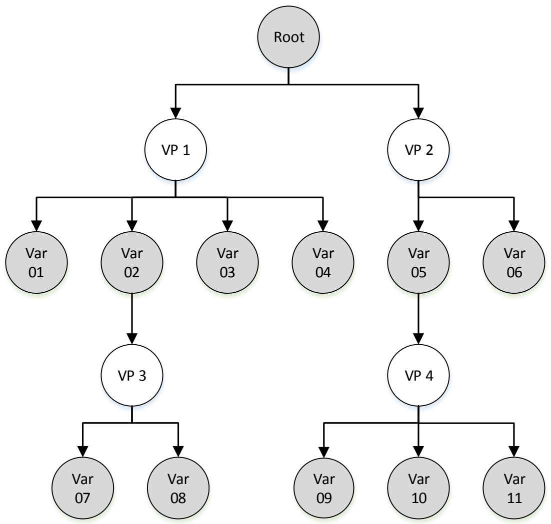


Figure 4: The variability structure of the process for the evaluation examples.

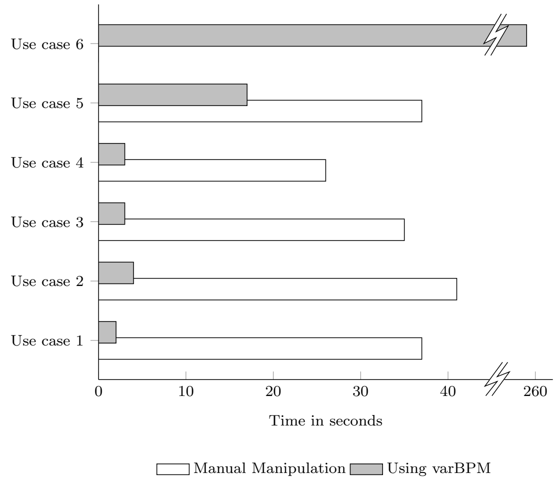


Figure 5: The results of the evaluation use cases. The grey parts are the time spent using the varBPM approach and the white parts states the time taken if a manual manipulation is used.

(documentation generation, workflow engine), the manual approach only reflects the time used for the creation of the bare process structure. The used process structure is part of a bigger process used for an on-demand manufacturing of spare parts for different car manufacturer.

**Use case 1:** For this use case, the time was measured that a domain expert needs to create a new process variant manually or using an existing feature model. The process setup consisted of four variation points (two top-level variation points and two variation points on lower levels) where a total number of twenty-seven different process variants were possible (for illustration, the variability structure can be seen in Figure 4). The number of other processes in the database of the BPM tool was considered to be low (20 other processes). The experiment was repeated with different experts and different process setups (the overall variability structure was kept the same but the process structures changed). The results of this use case are divided with the number of variation points to get a rough estimate for the time saving per variation point.

**Use case 2:** This use case is an addition to the first one, with the difference of a high number of other processes in the database (200 processes).

**Use case 3:** Is related to the topic of maintenance. In this scenario a process template was changed and all process variants should be updated. The domain expert was told that there is a number of six variants he needs to update providing only the name and the id of the changed process template. The size of the database was limited to 50 processes. The change to the template was a deletion/addition of a node. The results displayed in Figure 5 are normed to the update of one process.

**Use case 4:** This use case is an addition to the previous case, but with the difference that the domain expert was now told how the process variants where called (assuming that the domain expert was responsible for the creation of the process variants and exactly knows the variants).

**Use case 5:** In this situation, a new process variation was created by a process designer and the domain expert should now derive a new product variant out of it (in fact, a new variation for the Variation Point "VP 3" was developed). It is assumed that the processes are designed according to our proposed design rules. The number of other processes in the database was considered as low (20 processes). This use case also gives a good estimate on how much overhead is produced, to update an existing feature model.

**Use case 6:** In this case, a new feature model was developed according to the variability structure displayed in Figure 4 to generate a metric on how much overhead is produces for the initial creation of the feature model. To get a rough estimate on the overhead per variation point, this number is divided by four.

The results of "Use case 2" were surprising, since our developed approach performs worse in relation to the previous scenario. The reason for this is that the project now consists of ten times more processes, leading to a more time demanding search for the right processes. For humans, it was still quite easy to find the right processes since they were organised in a clear "human understandable" manner. As a result the increasing number of processes do not have a high influence to a manual manipulation if the processes are structured in a clear and meaningful way. Otherwise the time would increase more significantly.

To get a rough estimate of the break-even point, the following equation is used:

$$p \approx \frac{\text{Overall Overhead}}{\text{Average time saving}} = \frac{259}{4 \cdot 29} \approx 2.2 \qquad (1)$$

The overall overhead is the time spent to create the feature model ("Use case 6") and the average time saving is calculated using the average time saving per variation point multiplied by the number of variation points. Interestingly, when software product line techniques are applied to pure software systems, the break-even point is also located at around three systems (according to Pohl et al. (2005)).

### 4.5 Restrictions

Depending on the API of the used BPM Tool, your approach can be limited in terms of the available features. This means that if the BPM Tool only provides access to the basic process structure, our framework is limited to the creation of derived processes without the ability to automatically integrate the models into the capabilities of the BPM Tool (e.g. workflow engine).

## 5 RELATED WORK

As stated in the survey of Fantinato et al. (2012), major challenges in the field of business process variability modelling are related to the reaction time of process changes and of the creation and selection of the right business process variants, which are also main topics in our approach.

Derguech (2010) presents a framework for the systematic reuse of process models. In contrast to our approach, it captures the variability of the process model at the business goal level and describes how to integrate new goals/sub-goals into the existing data structure. The variability of the process is not addressed in his work.

Gimenes et al. (2008) presents a feature based approach to support e-contract negotiation based on web-services (WS). A meta-model for WS-contract representation is given and a way is shown how to integrate the variability of these contracts into the business processes to enable a process automation. It does not address the variability of the process itself but enables the ability to reuse business processes for different e-contract negotiations.

While our approach reduces the overall process complexity by splitting up the process into layers with increasing details, the PROVOP project (Hallerbach et al. (2009a,b) and Reichert et al. (2014)) focuses on the concept, that variants are derived from a basic process definition through well-defined change operations (ranging from the deletion, addition, moving of model elements or the adaptation of an element attribute). In fact, the basic process expresses all possible variants at once, leading to a big process model.

The work of Gottschalk et al. (2007) presents an approach for the automated configuration of workflow models within a workflow modelling language. The term workflow model is used for the specification of a business process which enables the execution of it in an enterprise and workflow management system. The approach focuses on the activation or deactivation of actions and thus is comparable to the PROVOP project for the workflow model domain.

Rosa et al. (2008) extends the configurable process modelling notation developed from Gottschalk et al. (2007) with notions of roles and objects providing a way to address not only the variability of the control-flow of a workflow model but also of the related resources and responsibilities.

The work of Leitner and Kreiner (2010) addresses the process variability through a bottom up approach by examining the possible configurations through the scan of the according ERP System (SAP). In contrast to this approach, we focus on an top down method to abstract the complexity of the underlying ERP System.

The Common Variability Language (CVL Haugen et al. (2013)) is a language for specifying and resolving variability independent from the domain of the application. It facilitates the specification and resolution of variability over any instance of any language defined using a MOF-based meta-model. A CVL based variability modelling and a BPM model with an appropriate model transformation could lead to similar results as presented in our work.

## 6 CONCLUSION AND OUTLOOK

The reuse of business process models is an important step for an industrial company to survive in a competitive market. With our work we have proposed a way to combine the benefits of software product line engineering techniques with the capabilities of a business process modelling tool to provide a framework for the systematic reuse of business processes. With the proposed design rules, our approach results in an automatic detection and propagation of new and/or changed business process variations. On the other hand it leads to an automatic integration of new assembled process variants into the BPM capabilities such as an automatic integration into a workflow engine, integration of responsibilities and resources, etc.

Our developed framework covers the variability of the process in two different ways: Through the linkage of different process variations to variation points and through a variable process structure (deletion / addition of nodes) in each layer. Due to the fact that our developed framework is in an early stage of usage, further research efforts would address the collection and evaluation of data regarding the evolution and maintenance of the process models. In this context, an integration of Six Sigma[4] into our framework is aimed to provide a complete framework from modelling and improving process models. Additionally the customization of the ERP system of the underlying system (in this case SAP) is an interesting topic, providing a complete framework for the topics of process modelling, execution and maintenance including the planing of the resources of the concrete production facility.

## ACKNOWLEDGEMENT

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[4] Six Sigma is a set of techniques and tools for a systematic management of process improvements based on quality management methods, including some statistical methods.

# Linking Business Process and Software System

Lerina Aversano, Marco di Brino, Paolo di Notte, Domenico Martino and Maria Tortorella
*Department of Engineering, University of Sannio, P.zza Roma, Benevento, Italy*
*aversano@unisannio.it, tortorella@unisannio.it*

Keywords: Business Process Modelling, Software modelling, Linking Process and software components.

Abstract: Enterprise necessitates to follow the rapid evolution of its business processes and rapidly adapt the existing software systems to its arising needs. A preliminary requirement is that the software subsystems are available and interoperable. A widely diffused solution is moving the adopted software solutions toward an evolving architecture, such as the one based on services. The objective of the research presented in this paper is to support the reuse of the existing software systems in a Service Oriented Architecture. The proposed solution is based on the idea that a Service Oriented Architecture can be obtained from a wide range of existing pieces of software. Such code components can be extracted from the existing software systems by identifying those ones supporting the business activities. Then, the paper proposes an approach for identifying the parts of software candidate to support a business process activity and it is based on the recovering of the links existing between the model of a business process and the supporting software systems. .

## 1 INTRODUCTION

The continuous changes of business requirements force enterprises to continually evolve the software systems they use for supporting the execution of their business processes. In this context, maintenance activities are required for adapting the software systems to the business process changes.

A business process consists of a set of activities performed by an enterprise to achieve a goal. Its specification includes the description of the activities and relative control and data flow. The software system supporting it is generally an application providing used during the execution of the business process activities. It is clear that a software component can be impacted, more or less significantly, from each business process change. The identification of the components impacted by the business change requirements is not always obvious to the maintenance workers. This is true especially when the change is expressed in terms of business activities with reference to the business context, or when the maintenance workers have not adequate information regarding the software system and its components with reference to such a kind context.

Therefore, it is very important an appropriate identification and comprehension of the relations existing between business process activities and software system components. Such a kind of comprehension provides a great help to the maintenance workers that are called to handle the change requests.

Considering the continuous change in the world of the information technology, there is an increasingly diffusion of Service Oriented Architecture, SOA. Its main strength is the easiness with which a service can be made available and used. This aspect suggests that the architecture of the old systems can be evolved towards a new system based on a service-oriented architecture.

Many approaches have been proposed in literature suggesting guidelines to identify services during the migration of legacy systems toward a service-based architecture (Khadka et al., 2013b) (Cetin et al., 2007). Nevertheless, in the authors knowledge, few papers propose the technical steps to be executed for achieving this goal. In (Balasubramaniam et al., 2008) an architecture-based and requirement-driven service-oriented reengineering method is discussed.

This method assume the availability of architectural and requirement information. The services are identified by performing the domain analysis and business function identification. Other approaches propose to evaluate services by performing either code pattern matching and graph transformation (Matos and Heckel, 2008), or feature location (Chen et al., 2005) or formal concept analysis (Chen et al., 2009). A detailed survey of the service identification methods is discussed in (Khadka et al., 2013a). In (Sneed, 2006), an automatic approach to evaluate candidate services is proposed. Candidate services are considered as groups of object-oriented classes evaluated in terms of development, maintenance and estimated replacement costs. In (Sneed et al., 2012), a tool is presented for supporting the reuse of existing software systems in a SOA environment by linking the description of existing COBOL programs to the overlying business processes.

This paper proposes a method for linking the process description with the components of a software system candidate to be reused in a service oriented architecture. The method exploits a formal description of a business process based on the BPEL language and calculates its textual similarity with the source code of the examined software system. The BPEL language has been chosen for the low effort needed to describe a business process by using it.

Section II describes the proposed approach and supporting tool; Section III describes the obtained experimental results; and concluding remarks and future works are discussed in the last Section.

# 2 APPROACH TO TRACEABILITY RECOVERY

The approach proposed aims at retrieving the traceability links between the business process activities and supporting software system components. It is based on the extraction of the identifiers of business process model and software components. It is composed of two processing phases:

- *Informationextraction* phase, regarding the extraction of semantic information from both business process and software system source code;
- *Traceabilityrecovery*, aiming at discovering the matching existing between the business information and software system components.

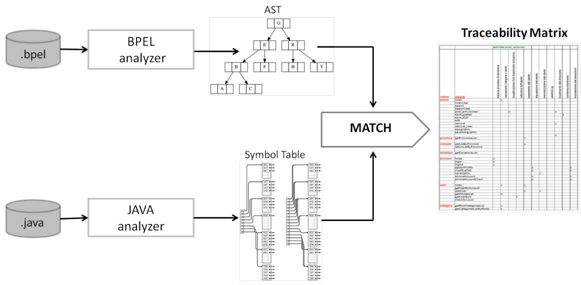


Figure 1: Overview of the approach fro traceability link recovery.

## 2.1 Information Extraction

The execution of this phase requires the implementation of a two parsers for analysing Java and BPEL files, and extracting all the needed information for performing the next traceability recovering. With this in mind, the JavaCC (Java Compiler Compiler) parser generator (*https : //javacc.java.net/*) was used. This tool reads a grammar specification and converts it into a Java program performing the top-down parser of a file written in the language based on the defined grammar. Then the regular expressions, context-free grammars and semantic rules were defined for describing both BPEL standard 2.0 and Standard Edition 7 for Java.

The implementation of the BPEL parser permits to construct the syntactic tree of the model description, which is the graph that allows expressing easily the process of derivation of a sentence using a grammar. The abstract syntax tree provides a structured view of the modelled business process, and excludes all the detailed information.

Figure 2 shows an example of a parse tree. It describes the business activities as brother nodes, while the son nodes indicate the artifacts needed for executing a business activity.

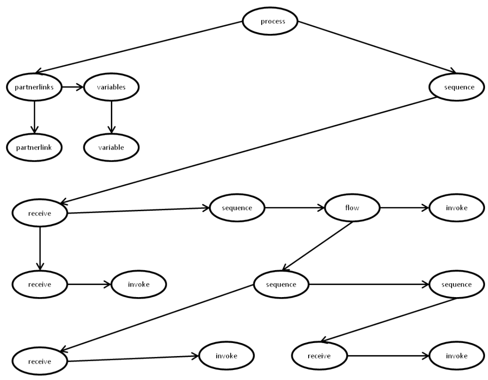


Figure 2: BPEL AST example.

After AST creation, further operations are planned for the correct insertion of comments. To identify the association between comments and code representing activities, it is necessary to make a visit to the tree in order to associate each comment node to the first brother node, which must not be a comment node. Once the association has been found. The analysis of the BPEL AST allows the identification of the identifiers for describing the business process.

The Java parser aims at constructing the symbol table of a supporting Java software systems, used to keep track of the source program constructs and, in particular, the semantics of identifiers, referred to packages, classes, methods, instance variables and local method variable declarations.

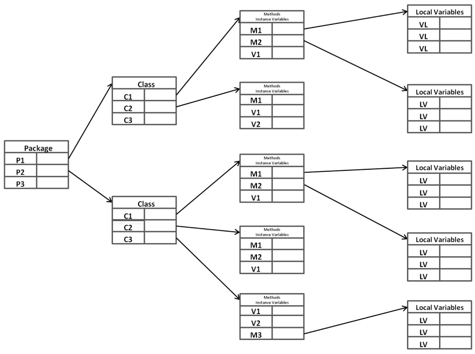


Figure 3: Java Symbol Table example.

The symbol table contains one record for each identifier, with some fields for its various attributes, such as its lexeme, type (e.g. identifier), identifier type that can be simple (integer, real, boolean, etc.), structured (vector or record) or a computational module, such as a function or procedure.

Figure 3 shows that the symbol table structure is hierarchical. On the first layer, there is a list of all packages declared in the project under consideration. Each record of this first layer contains a reference to another list, regarding the classes defined in the package in question. The set of all classes forms the second layer of the symbol table. Therefore, each class contains any references to objects declared in its interior, such as the methods and instance variables, and inner class. Each method can have another layer that represents the set of local variables it declares . Each inner class can be considered as a normal class, which may declare other methods, inner classes and instance variables. The procedure is iterated and accordingly the number of layers grows each time depending on the level of depth that will reach the analysis of the project concerned.

A preprocessing phase analyzes only the comments present within the various classes. Once it has been identified one, it is saved in a map, which will also allow saving the order of appearance of the various comments. After the preprocessing phase, the map is passed as an argument to the parser itself that analyses the comments for identifying additional semantic information coded in the code.

For each identifier, the symbol table records:

- *idName*: the name of the identifier to be saved;
- *kind*: the type of the identifier analyzed (class, method, package, etc ...);
- *scope*: the visibility of identifier (public, protected, private, etc ...);
- *args*: the method arguments;
- *typeRet*: the return type of the method or the type of a variable;
- *comments*: all comments associated with that identifier.

## 2.2 Traceability Recovery

After constructing the AST for BPEL and symbol table for Java, they are visited in a post-order manner for collecting the information necessary for the continuation of the analysis.

All the steps that follow are summarized in the chart drawn in Figure 4.

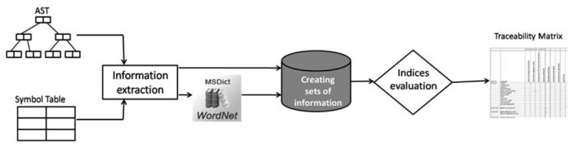


Figure 4: Information extraction phase.

The Information Extraction activity visits the AST BPEL and creates an array of BPEL activities, called *Activity*. Each *Activity* objects includes the BPEL file name, the task name and the set of terms related to the most important information; as an example, *name* and *operations* are kept for the *invoke* activities, while *portType* and *partnerLink* are considered wit reference to the *reply* and *receive* activities.

On the other side, the Java symbols table is entirely in order for identifying all the keys that correspond to the methods. Once one of it has been identified, a string set that contains the method name, any local variables name and inner classes that are contained within it, is created. Every single set of strings is in turn stored within a new map, which has as key a counter of the various set just created.

In accordance with the convention for identifiers nomenclature, when a term composed of two or more words is met, besides the full name, the individual terms are also included in the relevant collection of terms. Before being inserted in the collection, each term is normalized, i.e. all its characters are rendered tiny and all of the other symbols different from character and number are deleted. For example, if a method is called *GetCustomerName*(), the terms *GetCustomerName*, *get*, *customer* and *name* are included in the collection of terms. On the contrary, round brackets are non considered.

According to the above, different subsets of terms are created. For the *invoke* activity of the BPEL model, the following sets are created:

- a set including the terms contained in the argument called *operation*;
- a set including the terms contained in the argument called *name*;
- a complete set including the terms contained in the arguments called *operation*, *name*, *partnerLink*, *inputVariabile* and *outputVariable*.

The sets created for the *reply* and/or *receive* activities re the following:

- a set including the terms contained in the argument called *portType*;
- a set including the terms contained in the argument called *partnerLink*;
- a complete set that including the terms contained in the arguments called *portType* and *partnerLink*.

The terms of terms created for the Java methods are the following:

- a set including the terms of the considered method;
- a complete set including the names of the considered method, the names of its local variables and any inner classes, together with the single split words of the terms.

If no direct link is found between BPEL business activities and Java software methods, it is necessary to make a finer analysis. The first thing that is possible to do is the refinement of the terms, which requires their removal from the stopwords, or words that have no additional information content. In addition, for any term contained in the BPEL and Java full sets the set of synonyms are considered. The WordNet library, which is a lexical-semantic database for the English language, developed from Princeton University, is useful for performing this task.

For each term within the set of created words, a vector of synonyms is generated, which is added to the starting sets of terms.

### 2.2.1 Creating traceability matrix

After the creation of the sets of terms related to Java methods and BPEL activity, it is possible to proceed with the calculation of similarity between them, in order to properly fill the traceability matrix.

The coefficient used for the calculation of similarity is the Jaccard index. It is also known as the coefficient of Jaccard similarity, and it is a statistical index used to compare the similarity and diversity of sample sets. It is defined as the size of the intersection divided by the size of the union of the sets of samples:

$$J(A,B) = \frac{|A \cap B|}{|A \cup B|} \tag{1}$$

The value of this coefficient is defined in a range of values going from 0 to 1 (extremes included). In our case, $|A|$ represents the single set of terms obtained from the analysis of a Java method, while $|B|$ is the single set of terms obtained from the analysis of a BPEL activity. Therefore, we have $n$ sets of type $|A|$ and $m$ sets of type $|B|$, where $n$ represents the total number of methods identified taken from the Java parser and $m$ the total number of activities extracted from BPEL.

At this point, after calculated the coefficients, it is possible to generate the traceability matrix, which will be contained in an Excel file.

Generally, the traceablity matrix is composed as it follows :

- *row*: the $i-th$ row represents a method extrapolated from the Java parser, identified by a name but also by the package name and the name of its class;
- *column*: the $j-th$ column represents a basic BPEL activity extrapolated from the corresponding parser. It is identified by the BPEL file name containing the name of the activity and an argument called *name*;
- *intersect*: the $i,j$ cell ($i$ identifies the row and $j$ the column) represents the value of Jaccard index. Simply, the value of this cell is calculated on the sets of terms previously obtained by Java method $i$ and BPEL activity $j$.

### 2.2.2 Reporting matches

Whenever there is a correspondence between a Java method and a BPEL activity, the relative Jaccard index in the matrix is marked with a different color.

The most frequent case is that the analyzed Java method name is contained inside the parameter called *operation* (for *invoke* activity) or the parameter called *portType* (for *reply*/*receive* activities). For this reason, these first sets created based on information obtained from the BPEL activity are compared with each single set created on the basis of the analysis of the Java method name. A statistical study showed a real correspondence exists between a BPEL activity and a Java method if the similarity result has a value either greater of 0.85 or included between 0.33 and 0.55.

If the calculated index is not included in the indicated range, the analysis is done with all the sets created on the basis of the name contained inside the parameter called *name* (for *invoke* activity) or *parterLink* (for *reply*/*receive* activity). Even in this case, the Jaccard index is calculated between thesets of BPEL terms and the ones created with the Java methods; similarly, it exists a real correspondence between BPEL activity and Java method if the result has a value either greater of 0.85 or included between 0.33 and 0.55.

If the result is not in this range, the complete set is analyzed. The Jaccard index is calculated for all combinations of the complete set; afterwards, the greater index of the column is selected and the correspondence is marked if the index is great o equal to 0.33 (for *invoke* activity) or greater o equal to 0.55 (for *reply*/*receive* activity).

If in a column (associated with an activity) just one value different from 0 exists, it is marked a correspondence between the related Java method and BPEL activity, even if the value is not within any indicated range. This case is considered because that particular activity can be put in correspondence just with that Java method, even if the possibilities are low.

A prototype supporting tool has been implemented to process Java and BPEL sources code and produces a traceability matrix as output. Table 1 contains a sample output of the prototype. Each line represents a Java method of the analysed software system. The rows list: package name (*com.example*), Java class name (*TestProcess*) and method name (e.g. $getInfo()$). Each column, instead, represents a BPEL activity. It is possible to see: file name with extension .bpel (*process.bpel*), type of activity (e.g. *invoke*) and activity name (e.g. $getInfo$). The row-column intersection of this matrix contains the value of the Jaccard index, that is the numerical value of the correspondence that exists between BPEL activity and Java method.

In this example, the first analysis is done between the activity entitled $getInfo$ and all Java methods identified by the parser. It is possible to notice that between the value of the parameter called *name* of this activity and the Java method called $getInfo()$ there is a strong correspondence; in fact, their similarity in the traceability matrix includes the value 1, which is the greatest possible. This correspondence is indicated with color red within the Excel file.

Table 1: Example of matrix produced by prototype tool.

| | process.bpel **INVOKE** **(”getInfo”)** | process.bpel **RECEIVE** **(”receiveIn”)** | process.bpel **INVOKE** **(”callHelp”)** |
|---|---|---|---|
| com.example **TestProcess** **getInfo()** | 1 | 0 | 0,009 |
| com.example **TestProcess** **setInput()** | 0,1818 | 0,865 | 0 |
| com.example **TestProcess** **update()** | 0,3228 | 0,1243 | 0,076 |

The second analysis concerns activity *receiveIn*. Unlike the previous case, there is not an exact correspondence between this BPEL activity and any Java method. In any case, there is still a very high value (0,865) with the method called $setInput()$. This value will be compared from the set of Java method with one of all sets created for this type of activity, which is the set that contains the name of $portType$ argument, the set that contains the name of $partnerLink$ argument or the complete set with all information relating this activity. This correspondence will turn brown within the Excel file.

Finally, from the analysis of the last activity $callHelp$, it is possible to notice that the Jaccard values are very low, so the prototype will not highlight any possible match between this activity and any Java methods. Consequently, in the Excel file these values remain to their default color that is black.

# 3 RESULTS

The approach presented in the previous section has been validated in three case studies with the aim of assessing its effectiveness. Specifically three Java projects have been selected.

The first one is downloaded from the web; it deals with the management of a dealership. Originally, it was composed of 1066 Java files (code lines 124459) and 33 BPEL files but to facilitate the correctness verification of the results (operation done by hand) and the interpretation of the same results, only a five real interesting files have been selected.

The second and the third projects regard Java web project. The first one is written for private purpose; while the second one for managing a university exam. For these projects we asked to a third person to write the BPEL file modeling the business process starting from their knowledge without considering the source code. Also these last projects are small enough to permit a right manually verification.

The traceability matrix which contains the Jaccard indexes was generated For each projects. For every project we calculated:

- false positives: correspondences detected but not real;
- true positives: correspondences detected and real;
- false negatives: no correspondences found but actually present;
- true negatives: no correspondences found and not really present.

Table 2 contains a summary of the results obtained for the first case study. The low value of false negatives (just one) indicates that, when the correspondence exists, the proposed approach detect it correctly. The 15 occurrences of false positives are due to correspondences that do not exist: it is possible that the analyzed activity have a nomenclature similar to the one of a Java method, but there is no real correspondence between them.

Table 2: Experimental results for Dealership.

| Case Study | False Positives | False Negatives | True Positives | True Negatives |
|---|---|---|---|---|
| Dealership | 15 | 1 | 60 | 13769 |

Table 3: Precision, Recall, F-Measure for Dealership.

| Precision | Recall | F-Measure |
|---|---|---|
| 0.8 | 0.98 | 0.88 |

Table 4 shows a sinthesys of the results achieved for the second case study. In this case, a high number of false positives was obtained. The analysis of the correspondent Java source code indicates the use of meaningless names given to the various methods in the different classes. In particular, names are not relevant to the reference responsibilities (functionality).

Table 4: Experimental results for Groupon.

| Case Study | False Positives | False Negatives | True Positives | True Negatives |
|---|---|---|---|---|
| Groupon | 9 | 1 | 6 | 3413 |

Finally, Table 6 contains the results of the OnLine shop case study. It shows a discrete number of exact matches. Unlike the previous case, the cause of false positive was not associated with the inadequate nomenclature, but with the presence of some terms that subsequently brought with them a number of synonyms negatively influencing the results.

Table 5: Precision, Recall, F-Measure for Groupon.

| Precision | Recall | F-Measure |
|---|---|---|
| 0.4 | 0.86 | 0.55 |

Table 6: Experimental results for Online shop.

| Case Study | False Positives | False Negatives | True Positives | True Negatives |
|---|---|---|---|---|
| Online Shop | 2 | 2 | 5 | 3981 |

Table 7: Precision, Recall, F-Measure for Online shop.

| Precision | Recall | F-Measure |
|---|---|---|
| 0.71 | 0.71 | 0.71 |

## 3.1 Observation

Additional tests have been performed for considering the comments in the BPEL and Java files.

For associating a single comment to the BPEL activity, further nodes have been added to the AST. To capture the association between comments and relative source code, a visit of the tree is performed with the aim of associating every comment node to the first brother node, which obviously must not be in turn a comment node. Once the association has been found, a new record containing the comment is inserted within of the TreeMap of the considered node.

The validation of this variation of the approach was executed by considering the same 3 projects previously used. Comparing the new Jaccard indexes with the previous ones, it was found a deterioration of the results. This is due to considerable increase of terms included in the various sets. Thus, because of the considerable decrease of common terms in proportion to the totals, many of the real correspondence existing between Java method and BPEL activities (i.e. true positives) are not found. Thi experience shows that it is not suggested to consider comments for the creation of the set of terms for identifying a correspondence between BPEL and Java terms.

## 4 CONCLUSIONS AND FUTURE WORK

The paper presented an approach aiming at facilitating the reuse of the existing software systems that support business processes. In particular, this facilitation is provided by the ability of detecting the correspondences existing between source code components and activities, or processes, modelled by using the BPEL language.

The method implementation entailed the use of two parsers. The information extracted by using the parsers have been expanded and refined for being used in the traceability link recovery. The evaluation and selection of such correspondences has been performed by using the statistical indexes and similarity measure defined in the paper. A first analysis also included the comments in the code but it was observed that their use leads to worse results.

The preliminary results obtained by the proposed approach are encouraging and represent a starting point, for the identification of parts of the code from an existing software system with the aim defining new services to be used in a service oriented architecture. The approach is just based on the nomenclature used for naming methods and activities and does not analyse in details of the analysed software system. The values of $precision$, $recall$, $f-measure$ indicated in Tables 3, 5, 7 show the potential of the proposed approach.

The future work can concern the refinement of the selection of the correspondences in the matrix (refining the values in the range used for the analysis of Jaccard indexes), expanding test cases and extends the analysis also to WSDL files .

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# Improvement of Security Patterns strategy for Information Security Audit Applications

Lyazzat Atymtayeva[1] and Mahmoud Abdel-Aty[2]
[1]*Kazakh-British Technical University , Department of Information Systems Management, 050000, Tole bi str., 59, Almaty, Kazakhstan*
[2] *Zewail City of Science and technology, Giza, Egypt*
*l.atymtayeva@gmail.com, amisaty@gmail.com*

Keywords: Security patterns repository, application development, security ontology, fuzzy expert systems, information security audit.

Abstract: In the growing influence of information security level onto the business processes at the companies and organizations and their functioning by applying the software applications there is a necessity to develop systems with demanding level of security. Application developers are often confronted with difficulties in choosing or embedding security mechanisms that are necessary for building software secure applications, since this demands possessing expertise in security issues. This problem can be circumvented by involving security experts early in the development process. Usually it is accompanied with very high costs: experts in information security (IS) area are quite expensive specialists. An automation of some security implementation and evaluation tasks can reduce these costs and potentially increase the quality of IS strategies being developed and quality of IS audit processes. We believe that expert systems approach can be beneficial in achieving this automation. Though information security is a very broad field, encompassing many complex concepts, we are trying to develop a methodology of formalizing of IS knowledge to build a knowledge base for expert system that can serve as IS audit expert. With developing the special security patterns repository as a part of common framework for application development we can accumulate knowledge and expertise in the area of security, and help to software developers as well as IS audit stakeholders to have benefits from the processes of automation.

# 1 INTRODUCTION

Many current systems have serious security problems. We believe that a good way to have secure systems is to build applications and systems software in a systematic way, where security belongs to the part of the lifecycle.

The expert systems approach with developing of ontology can be beneficial in the building of framework for development of secure applications and for automation of processes of information security audit.

Building secure applications is a complex and demanding task developers often face. Meeting the specified security requirements, or embedding security mechanisms, however, is a process that involves expertise in the area of security, which most of the time software developers do not posses. Therefore, security experts often have to be involved during application development. This strategy entails high costs for software development; moreover the communication between developers and security experts is seldom smooth.

The same picture is observed in the processes of information security audit where attracting the security specialists often demands the high costs.

This paper suggests a different strategy for incorporating security in application development to solve the problems of secure software development and some processes of security audit.

It advocates the use of security patterns, by proposing a security patterns repository as a part of common framework for security applications development. The paper also addresses the issue of the limited usability of security patterns in software development, by customizing the patterns' structure so as to include security specific properties, such as threats and vulnerabilities, assets and controls. Thus, this paper aims to

- describe the adapted framework for development of secure applications
- propose an enhanced structure for security patterns
- describe a repository for security patterns in information security applications

Section 2 describes the framework for development of secure applications and security ontology. Section 3 deals with the security patterns in the development process, describes the improvement in creating security patterns repository based on ontology. In conclusions we present the summarizing of research work and define the directions for future research.

# 2 DESCRIPTION OF FRAMEWORK FOR SECURE APPLICATIONS DEVELOPMENT

The proposed adapted framework is intended for the effective introduction of security attributes in the process of application development. The initial version was proposed by Balopoulos Th. , et.al., 2006. Within the research process, security ontologies were first employed in order to explore how they can help developers better understand the application context and communicate with security experts and with the further expanding how it can use for the automation of the processes of information security audit.

Some results of these efforts have already been published in the works (Buschmann, F., et al., 1996 , Taylor, R.N., et.al., 2010). Following this, the research indicates that security patterns would be an appropriate tool for capturing security expertise, and that this can be formalized by employing security ontologies. Thus, based on the ontologies developed, we can explore the use of security patterns in the specific application contexts: we can design an appropriate structure for security patterns and a security patterns repository (Fernandez, E.B., 2006). This paper presents the adapted holistic framework employed, which can provide a useful solution for developers, especially those involved in the development of security critical applications as well as for the processes of the expert systems development in the area of information security.

This framework is depicted in Figure 1. It serves for incorporating security characteristics and accommodating security requirements in application development.

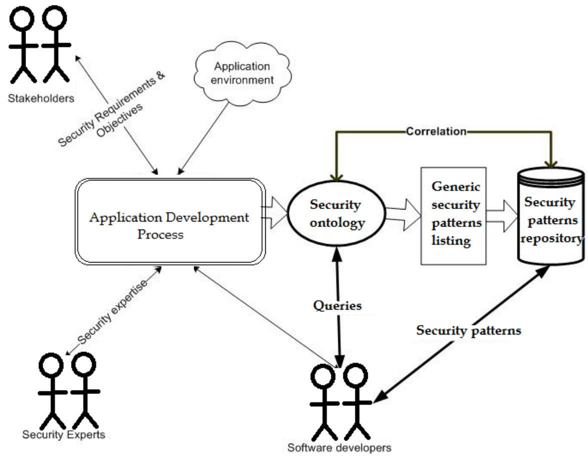


Figure 1: The adapted framework for secure application development.

By following the methodology of secure application development proposed by Balopoulos Th., 2006, we can create the adapted framework that is based on the principles of security ontology and automation of the processes of information security audit. This framework contains the security ontology which generates security patterns stored in repository, the part of application development process which can be presented as a reflection of the processing of a knowledge base for the best understanding of the specific security domain by software developers and stakeholders.

The adapted framework proposed in this paper constitutes an integrated approach that is addressed to developers for their applying the specialized knowledge and for supporting them in making use of recorded solutions to known security issues.

Key actors in this framework include

(a) the system stakeholders, i.e. the application users, the administrators and the management,

(b) security experts whose knowledge and expertise is needed to enhance the application development process by successfully introducing security features in applications, and

(c) the software developers. The latter are the ones that can use this framework for accommodating all different requirements and objectives with regard to security.

Information system stakeholders along with security experts and the software developers set the business and security objectives for the specific application. Existing security expertise is used along with the knowledge of the environment in which the specific application is going to be deployed in order to introduce environment specific security requirements. The development of corresponding ontology makes it possible to achieve the set goals by capturing and articulating the application context that can be used by developers. The principles of the processing of Knowledge Base in security area allow to create a security patterns and automate the process of the development of secure applications.

## 2.1 Different Approaches to Use Security Related Issues in Development

Regarding the use of security related issues in software development there are a lot of research and publications. The most of them study elaboration of different software design tools and methodologies like UMLsec (Mouratidis H., and Giorgini, P., 2004, Braz, F., et.al., 2008, Fernandez, E.B. and X.Yuan, 2010), Model-Driven Architecture (MDA) (Basin, D.A., et.al., 2006) , XML based models (Nagaratnam, N., et.al., 2005), industrial approaches like Microsoft solutions (Lipner, S. and Howard, M., 2005).

It is interesting to mention about the other types of security domain applications based on quantum information security. Classical computationally secure cryptosystems may be susceptible to quantum attacks, which means that attacks by adversaries able to process some levels of security via quantum information (Shor P.W., 1994, Biham E., at al 2000). These researches show that unitary bases can be central to both encryption of quantum information, at the same time the generation of states can be used in generalized quantum key distribution.

There are a lot of researches based on the ontological approach (Raskin et al, Dritsas,S.,et.al., 2005, Akerman, A. and Tyree, J., 2006, Voroviev, A. and Bekmamedova, N., 2010), and directions related to security patterns (Mouratidis H., and Giorgini, P., 2004).

We are going to focus on the approaches related to the use of security ontology of knowledge base.

## 2.2 The Security Ontology

An ontology is a description of the entities and their relationships and rules within a certain domain (Lazaros Gymnopoulos1, et.al. , 2006). Ontologies have been widely used within the fields of artificial intelligence, expert systems and the semantic web, mainly for knowledge representation and sharing. Computer programs can use ontologies for a variety of purposes including inductive reasoning, classification, a variety of problem solving techniques, as well as to facilitate communication and sharing of information between different systems. Ontologies are a great tool for defining and communicating the different ways in which people perceive a specific domain.

Ontology for the expert system is assigned to represent domain specific knowledge in the form which can be used by a computer to effectively operate on this knowledge.

Security ontologies are ontologies covering the domain of security .

In order to consider the combination of ontologies that related to the development of expert system in information security domain we can use proposed framework and all relations (Fenz S. and Ekelhart A. 2009, Maljuk A.A. 2010).

The Security Ontology shown in Figure 1 aims at covering and recording available knowledge regarding business and security objectives of a specific application development environment.

During the development of Expert systems for Information Security area (Atymtayeva L., et.al., 2014) we used adopted security ontology (Fenz S. and Ekelhart A. 2009, Maljuk A.A. 2010) that consists from four main entities and relationships between them(see Figure 2) .

The ontology is divided into two parts: the concepts representing information security domain knowledge (which actually are core concepts of the domain) and the concepts representing concrete information about considered organization, which are essential in measurement of its security level. These concepts are:

-Threat is a potential cause of an unwanted incident, which may result in harm to a system or organization [ISO].

-Vulnerability is a physical, technical or administrative weakness which could be exploited by threats.

-Control concept is used to mitigate vulnerabilities by implementing either organizational or physical measures.

-Asset is anything that has value to the organization [ISO]. Also assets are used to implement controls.

The most important relations between these concepts are:

-Threat threatens asset.

-Vulnerability is exploited by threat Severity.

-Vulnerability is mitigated by control.

-Control is implemented by asset Effectiveness.

-Asset has vulnerability.

The process followed for developing the security ontology, based on the method proposed by Akerman, A. and Tyree, J., 2006, is iterative and includes four phases: determining competency questions, enumerating important terms, defining classes and the class hierarchy, and finally, the instantiation of the hierarchy.

The competency questions which guided the security development process are loosely structured security oriented questions that the developed security ontology should be able to answer. These questions are taken from typical situations developers face when confronted with security requirements. Next, the most important terms with regard to security were enumerated; the most important of them formed ontology classes; others formed properties of classes and some were not used at all.

The main relations between ontology components and questionnaire process are depicted on the figure 2.

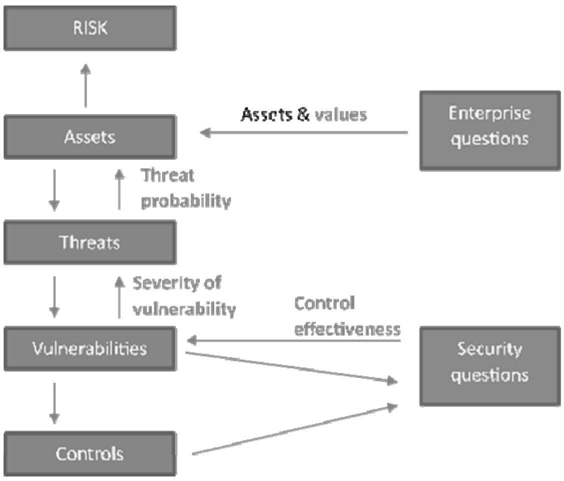


Figure 2: Security Domain Expert System Ontology.

For more precise definition of significance of questions and their ranking as well as the impact of the answers we use the special weight coefficients (Atymtayeva L., et.al., 2012). These coefficients allow make it easy the classification of questions during the process of their selection. This approach is very useful for developing of fuzzy expert system.

In adapted framework to examine the rigor of the Security Ontology developed we use queries (or specially constructed logic) expressed in the Fuzzy Relational Inference Language (FRIL). This language uses micro-logic, logic programming associates and support fuzzy logic, meta-programming and can be helpful for constructing the logic of queries (Protsenko N., Atymtayeva L., at all, 2012).

# 3 SECURITY PATTERNS IN SYSTEM DEVELOPMENT

In 1993 Gamma introduced patterns and since then their application in software development has continuously grown. This section is devoted to description of software and security patterns, and ways of designing the security repository.

## 3.1 Software and Security Patterns

Software patterns predefine a solution of recurring software development problems by specific way.

By using existing, well-proven experience in software development they can help promoting effective software design practices.

Each pattern may relate to the specific, repeating problem in software design and can be used to build applications with definite properties. So, "a pattern for software architecture describes a particular recurring design problem that arises in specific design contexts, and presents a well-proven generic scheme for its solution" (Buschmann et al. 1996). The solution scheme is defined by describing its constituent components, the existing relationships, and the ways in which they collaborate.

Patterns can provide a systematic and effective development of high-quality applications with defined functional and non-functional requirements. There are a lot of advantages of using patterns in software engineering (Buschmann et al. 1996).

A pattern system is defined as a collection of patterns for software architecture, including guidelines for their implementation, combination and practical use in software development. The main aspect for security patterns to be effectively used is its concise categorization within each pattern system.

The evolution of software patterns leaded to the modification of the concept of security patterns that was introduced in order to incorporate security techniques and best practices into the software development process.

A security pattern can be defined as a particular recurring security problem that arises in a specific security aspect, and presents a well-proven generic scheme for its solution (Schumacher 2003).

Application of security patterns can help bridge the gap between security professionals and system developers. Security patterns can assist developers implement effective security solutions and use them "in a right way". Security patterns are described by using a set of predefined elements, which compose the structure of the pattern, and their values (Balopoulos Th. , et.al., 2006).

The fundamental structure for describing and developing security patterns consists from the following six main elements (as was proposed by Schumacher 2003 and Kienzle et al. 2005):

*Name of Element \ Security Context (a.k.a. Motivation) \ Security Problem \ Security Solution \ Forces \ Related Patterns (a.k.a. Security Pattern Relations)*

The complementary elements of security pattern may include information about examples, resulting context, rationale, known uses, and etc.

## 3.2 Design of Security Patterns Repository

The problems in using security patterns based on the mostly ad hoc way accompanied by failed communication between security experts and the software developers generates the necessity in creating a security patterns repository.

In order to design the repository of security patterns, we first had to decide on their structure. In order to develop a security patterns' structure that would accommodate the security related requirements of using patterns, it was developed a security ontology, based on the one presented in (Dritsas et al. 2005). An ontology is a logical theory accounting for the intended meaning of a formal vocabulary. The intended models of a logical language using such a vocabulary are constrained by its logical commitment. An ontology indirect reflects this commitment (and the underlying conceptualization) by approximating these intended models (Mekhilef 2003). Thus, an ontology is the attempt to express an exhaustive conceptual scheme within a given domain, typically a hierarchical data structure containing all the relevant entities, their relations and the rules within that domain.

Based on the fundamental structure of security pattern by using the comprehensive information about security elements and relations between them together with their impact of each other we can construct the detailed security ontology depicted on figure 3 (Atymtayeva L., et al. 2014).

This ontology besides the main elements described before includes the additional elements (by adaption of the security ontology of Dritsas et al, 2005) such as Stakeholder\ Objective and Attacker \Attacks and their relations to the main model. All other elements has the relations of each other caused by the sources and reasons for their appearance in the model.

The ontology depicted in Figure 3, aimed to

(a) capture and express the most important security concepts for application development,

(b) describe the relations among these concepts,

(c) provide a common understanding and vocabulary of security issues among application developers,

and (d) facilitate the development of secure applications.

Thus, the developed ontology comprises a rich source of information regarding the security requirements of the specific application environment and, more importantly, is also a source of

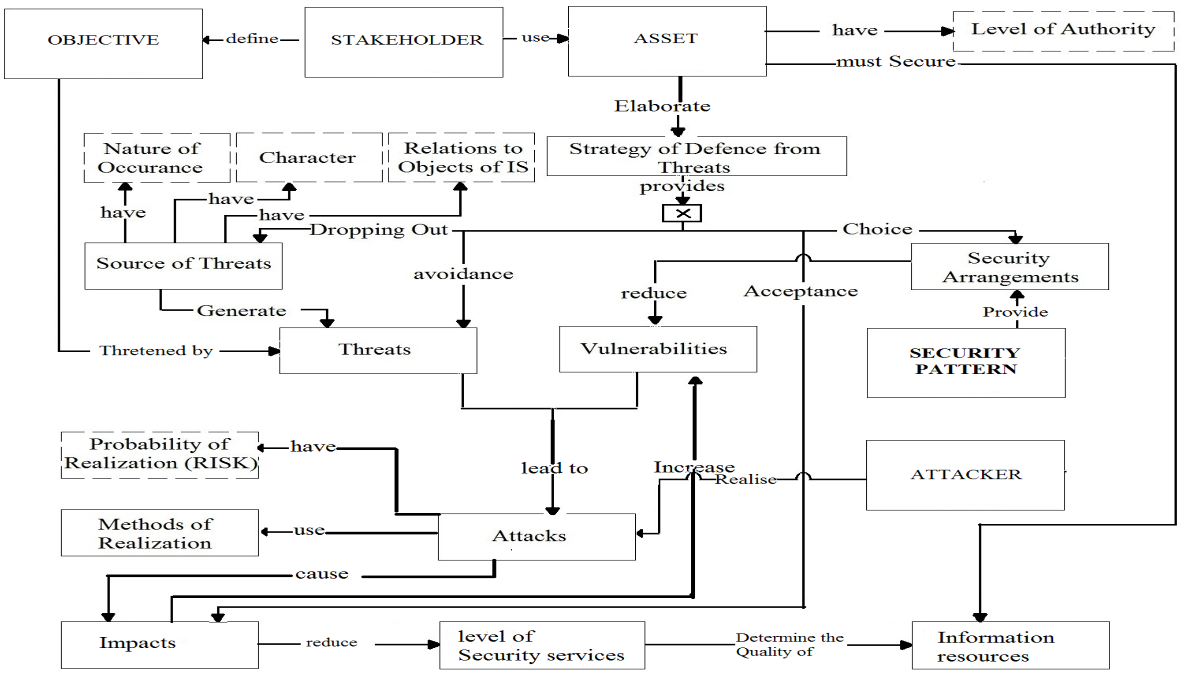


Figure 3: Detailed security ontology.

information regarding the way several key actors in the software development process view and judge those requirements.

# 4 CONCLUSION

This paper introduces some elements in improvement of representation security components with integration of software components by using security patterns and creating the security patterns repository. It was shown that this approach may be used to development of expert systems in security domain.

It was shown the improved security ontology with taking into account the elements of fuzzy expert system.

The security patterns repository and security patterns approach provides opportunity to software engineers, who are not security experts, to make the appropriate choices regarding security mechanisms and solutions, thus facilitating the development of secure applications. As a next step, this repository will be employed in the development of a security domain application, such as development of expert systems for information security active audit.

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# Software Implementation of Several Production Scheduling Algorithms

Vladimir Monov, Tasho Tashev and Alexander Alexandrov

*Institute of Information and Communication Technologies, Bulgarian Academy of Sciences*
*Acad. G. Bonchev str., bl. 2, 1113 Sofia, Bulgaria*

*vmonov@iit.bas.bg, ttashev@iit.bas.bg, akalexandrov@iit.bas.bg*

Keywords: Scheduling algorithms, production schedules, manufacturing process.

Abstract: The paper presents several production scheduling algorithms and their software implementation in an experimental program system developed in the program environment of the MATLAB system. The main characteristics and functionality of the individual software modules are described and illustrated by numerical examples.

## 1 INTRODUCTION

The theory of scheduling deals with problems for optimal allocation of scarce resources for implementation of various activities over time. One broad class of scheduling problems involves the dsign of production scheduling algorithms aimed at the optimization of technological machine and production capacity utilization in a production process. Typically, such a process is characterized by a number of jobs which have to be processed on a number of machines or work places in a given order or sequence. Depending on the specifics, scale and complexity of the particular production process the design of such schedules may represent a difficult and intractable task. It is obvious, however, that the use of optimal production schedules directly affects the production process leading to reduced costs and savings in energy and materials.

In this paper, we present a programme implementation of six production scheduling algorithms which are intended to solve some frequently arising scheduling problems in the production processes of small and medium companies. The algorithms have been developed in the course of a project supported by the National innovation fund as a part of an experimental programme system for production scheduling and inventory control in small and medium enterprises.

## 2 MODELS OF SCHEDULING PROBLEMS AND RELATED WORK

We shall consider deterministic models of scheduling problems where the number of jobs is denoted by n and the number of machines by m. Usually, the subscript j refers to a job while the subscript i refers to a machine. The following important data are associated with job j, (Pinedo, 2008).

**Processing time ($p_{ij}$)** The $p_{ij}$ represents the processing time of job j on machine i. The subscript i is omitted if the processing time of job j does not depend on the machine or if job j is only to be processed on one given machine.

**Release date ($r_j$)** The release date $r_j$ of job j may also be referred to as the ready date. It is the time the job arrives at the system, i.e., the earliest time at which job j can start its processing.

**Completion time ($C_j$)** This is the moment of time at which the job j comes out of the system. Clearly, the completion time of job j depends on the jobs that have been processed before it.

**Due date ($d_j$)** The due date $d_j$ of job j represents the committed shipping or completion date (i.e., the date the job is promised to the customer). Completion of a job after its due date is allowed, but then a penalty is incurred. When a due date must be met it is referred to as a deadline and denoted by $d_j$.

**Weight ($w_j$)** The weight $w_j$ of job j is basically a priority factor, denoting the importance of job j relative to the other jobs in the system. For example, this weight may represent the actual cost of keeping the job in the system. This cost could be a holding or inventory cost; it also could represent the amount of value already added to the job.

In the current literature it is commonly accepted to describe a scheduling problem by the triplet **$< \alpha \mid \beta \mid \gamma >$.** The **$\alpha$** field describes the machine environment and contains just one entry. The **$\beta$** field provides details of processing characteristics and constraints and may contain no entry at all, a single entry, or multiple entries. The **$\gamma$** field describes the objective to be minimized and often contains a single entry. Models of many scheduling problems can be described in terms of the triplet **$< \alpha \mid \beta \mid \gamma >$**, e.g., see (Brucker, 2007, Pinedo, 2008).

We shall illustrate the usage of the above notation by the following simple models.

- **$1 \mid \mid \Sigma C_j$** denotes the model of a scheduling problem where the jobs are processed on one machine, no preemptions are allowed and the objective is to minimize the sum of completion times of all jobs.
- **$1 \mid r_j \mid \Sigma C_j$** denotes a variant of the above problem where, in addition, release dates of the jobs are specified indicating times at which jobs can start their processing.
- **$1 \mid r_j, prmp, prec \mid C_{max}$** denotes the model of a scheduling problem with one machine where the jobs have release dates, their processing can be interupted, there are precedence restrictions and the objective is to minimize the processing time of all jobs.

There are different types of schedules and one of the first classification of various scheduling problems can be found in the seminal work of Conway et al., (1967). A comprehensive study of scheduling algorithms and their complexity is presented in Lawler et al., (1993). Deterministic scheduling problems are considered in Graham et al., (1979) and a survey of scheduling problems subject to various constraints is given by Lee, (2004). Special classes of scheduling problems with penalties and non-regular objective functions are considered by Baker and Scudder, (1990) and Raghavachari, (1988). A survey of scheduling problems with job families and problems with batch processing, can be found in the work of Potts and Kovalyov (2000). In the more recent literature, production scheduling is also attracting a considerable amount of research. A classification, models and complexity results on problems for parallel machine scheduling are given by (Edis et al., 2013 and Prot et al., 2013). References (Allahverdi et al., 2008), (Janiak et al., 2015) and (Kovalyov et al., 2007) represent surveys on scheduling problems with setup times, due windows and jobs with fixed intervals, respectively. Tools for multicriteria scheduling are desribed in (Hoogeveen, 2005) and architectures of manufacturing scheduling systems are discussed in (Framinan and Ruiz, 2010). Finaly, it should be noted that the monographs (Brucker, 2007) and (Pinedo, 2008) give a systematic view of the research work and advancement in the area of scheduling theory and its applications.

## 3 GENERAL DESCRIPTION OF THE PROGRAM SYSTEM

Our experimental software system is designed to solve a number of problems arising in the technological management of small and medium-size enterprises. Two main groups of problems are under consideration. The system architecture is shown in Figure 1.

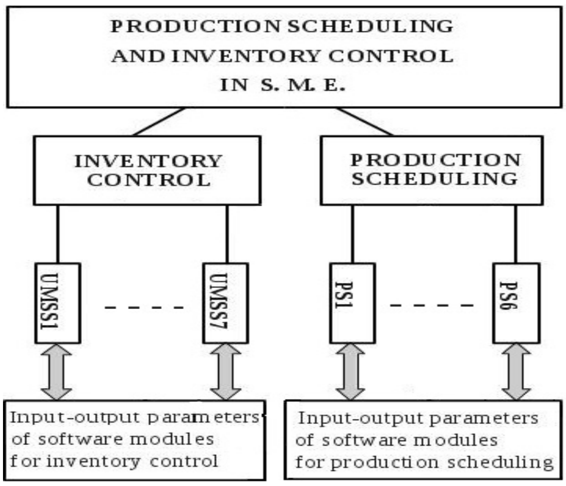


Figure 1: System architecture.

It is seen that it includes two main branches, corresponding to the two groups of problems related with inventory control and production scheduling, respectively. Each branch in turn includes algorithmic software modules to solve specific tasks in the group. The programme system provides an interactive mode of operation in which the user can choose one of the two main branches and then starts a specific algorithmic module depending on the particular problem to be solved. In the process of system operation, input-output parameters of the system turn out to be input-output parameters of the currently active module.

The description of program modules of UMSS1 to UMSS7 in Figure 1, as well as the specific tasks to be solved by means of these modules were presented in (Monov and Tashev, 2011). Program modules from PS1 to PS6 will be described in the next section.

The graphical user interface of the system is simplified and it includes three main modules:

**main_window -** interface module, bringing up the main menu of the system;

**start1_interface -** interface module, displaying the inventory control menu;

**start2_interface -** interface module displaying the production scheduling menu.

The computer screen with the interface module **main_window** is shown in Figure 2 and the launch of this module in fact starts the system.

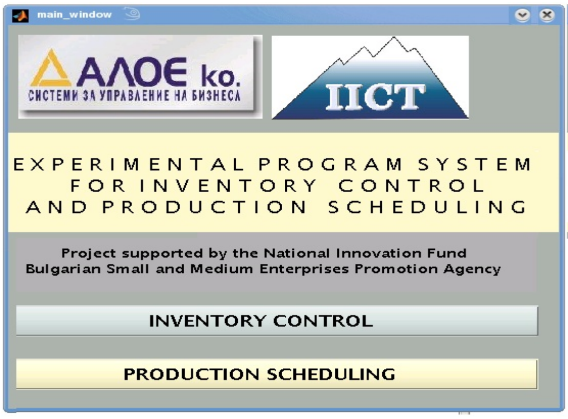


Figure 2: System main window.

By choosing one of the two groups of tasks, the user can start the corresponding interface module which displays the menu for choosing a particular task to be solved. The computer screen of the interface module displaying the production scheduling menu is shown in Figure 3.

Each of the algorithmic software modules can work within the program system and as an independent module as well. In the second case it is necessary the name of the module to be typed in the command window of MATLAB. Then the introduction of input data and the output of results is accomplished by means of the system facilities of the MATLAB programming environment. Each module includes the following capabilities.

- Data input is performed in an interactive mode from a standard keyboard, and the results are displayed automatically after completing the work of the algorithm.
- In each module, a check for correctness of the input data is performed, an opportunity to reintroduce incorrectly entered data is foreseen, and also an opportunity is provided to exit the module during data entry before the start of the computational algorithm.
- Depending on the specifics of the particular algorithm, the software module displays the necessary messages concerning the problem being solved.
- After completion of the work and upon a request of the operator, input data and results can be stored in a specified user file outside of the system for further processing and analysis. The name of this file is defined by the user.

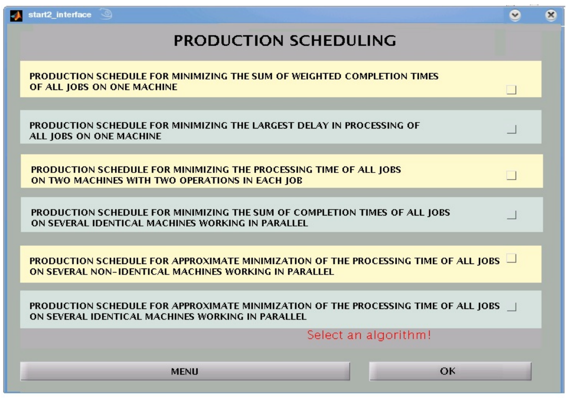


Figure 3: Interface module **start2_interface**.

## 4 SOFTWARE MODULES FOR PRODUCTION SCHEDULING

In this section, we briefly describe the scheduling problems under consideration and illustrate the work of the corresponding software modules intended to solve these problems.

### 4.1 Production schedule for minimizing the sum of weighted completion times of all jobs on one machine - $\Sigma\, w_i C_i$

Problem formulation. The scheduling problem is characterized by one machine environment, i.e. n=1 and m jobs. Each of these jobs has one operation (consisting of a single operation), with processing time $p_j$. Clearly, in any random order of implementation of the jobs, they will all be fulfilled in time $\Sigma\, p_j$ . The completion times and weights of the jobs are $C_j$ and $w_j$, respectively. The problem consists in finding such a sequence of jobs processing which will minimize the weighted sum of completion times of all jobs. Thus, the implemented algorithm minimizes the quantity $\Sigma w_i C_i$ .

Input data. These are: the number m of jobs, the numbers $p_j > 0$ and numbers $w_j > 0$.

Output data. This is the optimal schedule indicating the sequence of processing of jobs that will minimize the quantity $\Sigma w_j C_j$. The optimal value of $\Sigma w_j C_j$ is also computed.

The above problem is solved by means of the software module **PS1.** The work of the module is illustrated by the following numerical example.

Example 1. Consider the scheduling problem with three jobs which have to be processed on one machine with numerical data given in Table 1.

Table 1: Numerical data for Example 1.

| Jobs, $J_j$ | Processing times, $p_j$ | Weights, $w_j$ |
|---|---|---|
| $J_1$ | 4 | 3 |
| $J_2$ | 2 | 1 |
| $J_3$ | 5 | 4 |

The software module **PS1** computes the quantities $q_j = p_j / w_j$ , finds the optimal schedule and the minimal value of $\Sigma\ w_i C_i$ . The output results are written in a user file which is given below.

PRODUCTION SCHEDULE FOR MINIMIZING THE SUM OF WEIGHTED COMPLETION TIMES OF ALL JOBS ON ONE MACHINE - $1 \mid\mid \Sigma\ w_i C_i$

Optimal schedule

Job: 3
- Processing time ($P_3$): 5
- Weight ($W_3$): 4
- Value q = $P_3$ / $W_3$: 1.25
- Completion time ($C_3$): 5
- Value ($W_3C_3$): 20

Job: 1
- Processing time ($P_1$): 4
- Weight ($W_1$): 3
- Value q = $P_1$ / $W_1$: 1.3333
- Completion time ($C_1$): 9
- Value ($W_1C_1$): 27

Job: 2
- Processing time ($P_2$): 2
- Weight ($W_2$): 1
- Value q = $P_2$ / $W_2$: 2
- Completion time ($C_2$): 11
- Value ($W_2C_2$): 11

Minimal value: Sum (WjCj) = 58

## 4.2 Production schedule for minimizing the largest delay in processing of all jobs on one machine - 1 | | Lmax

Problem formulation. In this case, the objective is to find an optimal schedule for the operation of one machine under the following conditions. The number of jobs to be processed is m and for each job j two variables are given: the processing time $p_j$ and the due date $d_j$. All jobs are available at the initial time and this allows them to be processed in any order. If you choose such an order, then the job j will be completed at the time $C_j$ and thus the delay of the job is $C_j - d_j$. For any chosen order (sequence) of processing, the delays of the jobs can be calculated. Each particular order of jobs processing is characterized by the maximum value among these delays. The aim in this production scheduling problem is to find this sequence of jobs processing for which this maximum delay is as small as possible.

Input data. These are: the number m of jobs, the numbers $p_j > 0$ and numbers $d_i > 0$.

Output data. This is the optimal schedule indicating the sequence of processing of jobs that will minimize the maximal delay $L_{max}$ of jobs. The minimal value of $L_{max}$ is also computed.

The above problem is solved by means of the software module **PS2.** The work of the module is illustrated by the following numerical example.

Example 2. Consider the scheduling problem with three jobs which have to be processed on one machine with numerical data given in Table 2.

Table 2: Numerical data for Example 2.

| Jobs, $J_j$ | Processing times, $p_j$ | Due dates, $d_i$ |
|---|---|---|
| $J_1$ | 3 | 4 |
| $J_2$ | 5 | 6 |
| $J_3$ | 2 | 5 |

The software module **PS2** computes the optimal sequence of jobs processing which is $<J_1, J_3, J_2>$ and the minimal value of $L_{max}$ which is $L_{max} = 4$. For comparison, if the jobs are processed in the order $<J_2, J_3, J_1>$ then the corresponding delay is 6. The output results are written in a user file which is given below.

PRODUCTION SCHEDULE FOR MINIMIZING THE LARGEST DELAY IN PROCESSING OF ALL JOBS ON ONE MACHINE - 1 | | LMAX

Optimal schedule

Job: **1**
- Processing time ($P_1$): 3
- Due date ($D_1$): 4
- Completion time ($C_1$): 3
- Delay $C_1$-$D_1$: -1

Job: **3**
- Processing time ($P_3$): 2
- Due date ($D_3$): 5
- Completion time ($C_3$): 5
- Delay $C_3$-$D_3$: 0

Job: **2**
- Processing time ($P_2$): 5
- Due date ($D_2$): 6
- Completion time ($C_2$): 10
- Delay $C_2$-$D_2$: 4

The largest delay in the processing of jobs: $C_2$-$d_2$ = 4 for job 2

## 4.3 Production schedule for minimizing the processing time of all jobs on two machines with two operations in each job F2 | | Cmax

Problem formulation. In this production scheduling problem we have two machines which, in general, are different. The number of jobs to be processed is m and each of these jobs has two operations. For each job the first operation is performed on machine 1 and lasts $a_j$ time units and the second operation is performed on machine 2 and has a length $b_j$. The essential question in this problem is that for each job the second operation can be run on a machine 2 only after the complete implementation of the first operation on the machine 1. It is necessary to find such a sequence of jobs processing, in other words to find such a schedule, at which the execution of all the jobs is completed in the shortest time.

Input data. These are: the number m of jobs, the processing times $a_j$ of the first operations and the processing times $b_j$ of the second operations.

Output data. This is the optimal schedule indicating the sequence of processing of jobs on the two machines that will minimize the overall processing time. The value of this time is also indicated.

Remark. It should be noted that the optimal sequence for the first machine is performed by consecutively processing the first operations of the jobs running on the machine immediately one after another. The second operations of the jobs, however, are executed on the second machine only after the first operations has been completed on the first machine.

The above problem is solved by means of the software module **PS3.** The work of the module is illustrated by the following numerical example.

Example 3. Consider the scheduling problem with three jobs which have to be processed on two machines with numerical data given in Table 3.

Table 3: Numerical data for Example 3.

| Jobs, $J_j$ | Processing times $a_j$ of the first operations on Machine 1 | Processing times $b_j$ of the second operations on Machine 2 |
|---|---|---|
| $J_1$ | 4 | 1 |
| $J_2$ | 2 | 5 |
| $J_3$ | 6 | 3 |

The software module **PS3** computes the optimal sequence of jobs processing which is $<J_2, J_3, J_1>$ and the minimal processing time of all jobs is 13. For comparison, if the jobs are processed in the order $<J_1, J_2, J_3>$ then the corresponding processing time is 15. The output results are written in a user file which is given below.

PRODUCTION SCHEDULE FOR MINIMIZING THE PROCESSING TIME OF ALL JOBS ON TWO MACHINES WITH TWO OPERATIONS IN EACH JOB: F2 || CMAX

Optimal schedule

Job: **2**
- Processing time of operation 1 for this job: 2
- Processing time of operation 2 for this job: 5

Job: **3**
- Processing time of operation 1 for this job: 6
- Processing time of operation 2 for this job: 3

Job: **1**
- Processing time of operation 1 for this job: 4
- Processing time of operation 2 for this job: 1

Minimum total execution time of all jobs : 13

## 4.4 Production schedule for minimizing the sum of completion times of all jobs on several identical machines working in parallel - P || Σ Cj

Problem formulation. The following production scheduling problem is considered. There are n identical machines working in parallel. The number of jobs to be processed is m and each of these jobs has one operation. The jobs processing times are $p_j$ . For each job the processing time is the same for all machines (identical machines). It is necessary to find the optimal schedule which minimizes the sum of completion times of all jobs.

Input data. These are: the number m of jobs, the number n of machines, processing times $p_j$ .

Output data. This is the optimal schedule indicating the particular jobs processing on each machine and the sequence at which these jobs are executed. The optimal value of the sum of completion times ΣC j is also computed.

Remark. The implemented algorithm is based on priorities and it uses the rule SPT (shortest processing time first). The point is that all jobs are ranked in order of monotonically increasing times $p_j$ . The first few jobs are distributed on the machines and later, when a machine completes its work, the next job is placed on this machine.

The above problem is solved by means of the software module **PS4.** The work of the module is illustrated by the following numerical example.

Example 4. Consider the scheduling problem with seven jobs which have to be processed on three machines with numerical data given in Table 4.

Table 4: Numerical data for Examples 4 and 6.

| Processing time $p_1$ of Job 1 | Processing time $p_2$ of Job 2 | Processing time $p_3$ of Job 3 | Processing time $p_4$ of Job 4 |
|---|---|---|---|
| 5 | 3 | 8 | 2 |
| **Processing time $p_5$ of Job 5** | **Processing time $p_6$ of Job 6** | **Processing time $p_7$ of Job 7** | |
| 4 | 6 | 7 | |

The software module **PS4** computes the optimal sequence of jobs processing on each machine and the minimal value of the sum of completion times of all jobs. This value is found to be 51. For comparison, if the jobs are processed in the order <$J_1$, $J_2$, $J_3$, $J_4$, $J_5$, $J_6$, $J_7$> then the corresponding value of the sum is 58. The output results are written in a user file which is given below.

PRODUCTION SCHEDULE FOR MINIMIZING THE SUM OF COMLETION TIMES OF ALL JOBS ON SEVERAL IDENTICAL MACHINES WORKING IN PARALLEL
– P || Σ Cj

Optimal Schedule

**Machine:1**

- Job:**4**
- Processing time of this job:2

- Job:**1**
- Processing time of this job :5

- Job:**3**
- Processing time of this job:8

**Machine:2**

- Job:**2**
- Processing time of this job:3

- Job:**6**
- Processing time of this job:6

**Machine:3**

- Job:**5**
- Processing time of this job:4

- Job:**7**
- Processing time of this job:7

Sum of completion times of all jobs: Σ Cj :51

## 4.5 Production schedule for approximate minimization of the processing time of all jobs on several non-identical machines working in parallel - Q || $C_{max}$

Problem formulation. There are several machines which are not identical. This means that they have different speeds of operation, but in all other aspects of their capabilities are the same. A number of jobs are to be processed, each of which consists of a single operation. Any job can be executed on any machine. The absolute speeds of operation of machines are known in advance. The algorithm calculates their relative speeds. The jobs processing times on *the slowest* machine are known. All machines and jobs are available at the initial time of operation. The aim is to allocate jobs for execution on machines in such a way as to obtain as little as possible processing time of all jobs. The algorithm gives *approximate* (suboptimal) solution of this problem.

Input data. These are: the number of machines and their absolute speeds of operation, the number of jobs and their processing times on the slowest machine.

Output data. The obtained schedule and the processing time of all jobs.

Remark. The algorithm finds the relative speeds of the machines and arranges them in order of decreasing of these speeds. Then it arranges jobs in order of decreasing of their individual processing times on the slowest machine. The algorithm allocates jobs on machines by putting the first of waiting jobs on the fastest free (released) machine.

The above problem is solved by means of the software module **PS5.** The work of the module is illustrated by the following numerical example.

Example 5. Consider the scheduling problem with five jobs which have to be processed on three machines. The absolute speeds of operation are given in Table 5 and the processing times of the jobs on the slowest machine are given in Table 6.

Table 5: Absolute speeds of operation.

| Machine 1 | Machine 2 | Machine 3 |
|---|---|---|
| 2 | 4 | 6 |

Table 6. Processing times.

| Job 1 | Job 2 | Job 3 | Job 4 | Job 5 |
|---|---|---|---|---|
| 3 | 4 | 5 | 6 | 7 |

The software module **PS5** computes a schedule which approximately minimizes the processing time of all jobs on the three machines. The output results are written in a user file which is given below.

PRODUCTION SCHEDULE FOR APPROXIMATE MINIMIZATION OF THE PROCESSING TIME OF ALL JOBS ON SEVERAL NON-IDENTICAL MACHINES WORKING IN PARALLEL - Q || Cmax

Computed schedule

**Machine:3**
-Relative speed of operation:3
-Total processing time of this machine:3.6667

No1
Job:**5**
-Processing time of this job:2.3333

No2
Job:**2**
-Processing time of this job:1.3333

**Machine:2**
-Relative speed of operation:2
-Total processing time of this machine:4.5

No1
Job:**4**
-Processing time of this job :3

No2
Job:**1**
-Processing time of this job:1.5

**Machine:1**
-Relative speed of operation:1
-Total processing time of this machine:5

No1
Job:**3**
-Processing time of this job:5

Maximal processing time Cmax=5 obtained on machine:1

## 4.6 Production schedule for approximate minimization of the processing time of all jobs on several identical machines working in parallel - P || C max

Problem formulation. In this production scheduling problem there are m identical machines working in parallel. The number of jobs is n and each of them consists of one operation. The processing times of jobs $p_j$ are known and for each job the processing time is the same for all machines. The aim is to allocate jobs for execution on machines in such a way as to obtain as little as possible processing time of all jobs. The algorithm gives *approximate* (suboptimal) solution of this problem.

Input data. These are: the number of machines, the number of jobs and their processing times.

Output data. The obtained schedule and the processing time of all jobs.

Remark. The software module implements an approximate algorithm using the LPT rule (longest processing time first). At first all jobs are ranked in order of monotonically decreasing times $p_j$. Observing the LPT rule, the first ordered jobs are placed on the available machines. Next, as a machine becomes free the next job is executed on it. The algorithm enables us to estimate the deviation from the optimal value of the problem. If we denote by C max_opt the minimal processing time of all jobs, then the implemented algorithm ensures execution time, which is less than or equal to 4/3 C max_opt. The above problem is solved by means of the software module **PS6.** The work of the module is illustrated by the following numerical example.

Example 6. Consider the scheduling problem with seven jobs which have to be processed on three machines. The jobs processing times are the same as in Example 4 and are given in Table 4.

The software module **PS6** computes a suboptimal schedule including the following sequence of jobs processing.

- Job3, Job2, Job4 are processed on Machine 1,
- Job7 and Job5 are processed on Machine 2,
- Job6 and Job1 are processed on Machine 3.

In this case the maximal processing time is $C_{max}$=13 which is obtained on Machine 1.

# 5 CONCLUSIONS

The paper presents a software implementation of six algorithms intended to provide solutions to some basic production scheduling problems and to facilitate the production management in small and medium enterprises. Our experimental program system is open for adding new modules and in a future work, a library of scheduling algorithms and software modules can be developed and incorporated in the system. In particular, the system capabilities can be extended by using more elaborate mathematical models of manufacturing processes taking into account various processing characteristics and constraints and different machine environments.

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# Context Emergence Using Graph Theory

## *Defining and Modeling Context for Industrial Assets Using Graphs*

Bharath Rao and Arila Atanassova-Barnes
*GE Software,2623 San Ramon Blvd, San Ramon, CA, USA*
*rao@ge.com, arila.barnes@ge.com*

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Abstract: Traditionally, context in software is modeled as a global variable, static class, or similar mechanisms that are initialized when an application is loaded and updated periodically through the lifetime of the application as the end user interacts with instructions. This approach is limited to customizations, personalization and initialization based on previously captured, mostly static information. It is a replay of a previous state. In this paper we propose a new approach to defining and modeling context for software applications using graphs. Context is fundamentally interaction-based and comes into play when one entity interacts with another to achieve a goal in a given environment constrained by time and location. By capturing the interactions between entities in a graph, context becomes emergent rather than declarative and can be learned from user interactions. The context is discovered by first-degree graph traversal of interacting entities. The discovered context is used to achieve context sensitive goals in environments with a large number of interconnected entities such as the Internet of Things (IoT).

## 1 INTRODUCTION

To support decisions based on goals and actions in industrial scenarios, it is critical to detect and evolve context of operational environments in such a way that the system remains adaptive and dynamic and can react to changing goals in real time (Loren, 2015).

For the purpose of this paper we start with the following definition of context: 'Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.' (Abowd et al., 1999)

Entities can be modeled as vertices in a graph and relationships can be modeled as edges. This enables us to represent any set of relationships as a graph. Using graph relationships and paths, the use of simple graph operations enables us to determine context and leverage it to achieve goals. We present a novel approach that allows context to emerge organically based on the entity relationship graph rather than being explicitly maintained.

## 2 GRAPH APPROACH TO CONTEXT

### 2.1 Information as a Graph

All known information at any given time may be represented as a graph. The graph itself is made up of a set of vertices and edges.

$$G = (V, E)\,. \tag{1}$$

In an open world assumption, all vertices are presumed to exist and a graph can simply be defined as a set of edges bounded by two vertices. Such a graph can be described as a directed, labeled multi-graph. Such multi-graphs may be modeled as a set of triples (W3C, 2014), each triple $t$ is a 3-tuple containing the subject $s$, predicate $p$ and object $o$ representing an arc in a directed graph. The subject is the vertex at the origin of the arc, the object is the destination and the predicate is the label on the arc.

$$t = (s, p, o)\,, \tag{2}$$

$$\mathcal{G} = \{t\}\,. \tag{3}$$

Maintaining the relationship graph then simply becomes a matter of adding a triple when a new relationship is formed and removing a triple when a relationship is dissolved and archived.

## 2.2 Context as a Function of Graph

For context modeling we present a light asset-centric ontological approach (RDF) and leverage graph theory for both the storage of the asset related data and the inference of new contexts dependent on goals.

As edges are added and removed over time, a characteristic pattern develops around an entity as an emergence (Lewes, 1874). This emergent context may be used to avoid manually maintaining a context.

More context does not necessarily improve the accuracy of the inference in a considerable manner. (Guan et al., 2007) Rather than creating an exhaustive context model, our approach is to let it grow organically.

Definition 1: *The context of any entity is the set of its first-degree connections.*

$$C_\varepsilon = \{t \mid s = \varepsilon \lor o = \varepsilon\} . \quad (4)$$

The entity $\varepsilon$ may be connected to other entities or may simply point to a value. This includes both inbound and outbound connections in case of directed graphs.

Definition 2: *The common context between any two entities is the intersection of their individual contexts, i.e., their first-degree connections.*

$$C_{AB} = C_A \cap C_B . \quad (5)$$

Definition 3: *Emergent Context of entities is the union of their contexts that naturally arises as old connections dissolve and new connections form.*

$$C_E = C_A \cup C_B . \quad (6)$$

Definition 4: *Goal based context is a subset of the emergent context that is relevant for the aforesaid goal.*

$$C_G \subseteq C_E . \quad (7)$$

## 2.3 Graph Path Notation

We introduce the following notation for describing sets of graph paths from $\mathcal{G}$, which may be effectively used as queries.

A path $P$ is a non-empty sub-graph of $\mathcal{G}$ such that the edges $e_i$ connect one vertex to the next and every vertex $x_i$ is distinct.

$$P = \{(x_0\, e_0 x_1), (x_0 e_1 x_1), \ldots, (x_{k-1} e_k x_k)\} ,$$
$$e_i = {}^{>}e_i \lor {}^{<}e_i , \quad (8)$$

Where ${}^{>}e_i$ and ${}^{<}e_i$ represent outgoing and incoming arcs from vertex $x_i$ respectively.

Let the path expression ${}^{=}s_i$ be the subset of all paths in $\mathcal{G}$ that start with vertex $s_i$.

$${}^{=}s = \{P \mid x_0 = s\} . \quad (9)$$

Let the path expression ${}^{>}p$ be the subset of all paths in $\mathcal{G}$ that start from any subject having a predicate $p$ (i.e., all paths beginning from any vertices and an outgoing edge with label $p$) to any vertices.

$${}^{>}p = \{P \mid (x_0\ {}^{>}e_0\, x_1) = (x_0\, p\, x_1)\} . \quad (10)$$

Let the path expression ${}^{<}p$ be the subset of all paths in $\mathcal{G}$ that start from any object having a predicate $p$ (i.e., all paths beginning from any vertices and an incoming edge with label $p$) to any vertices.

$${}^{<}p = \{P \mid (x_0\ {}^{<}e_0\, x_1) = (x_0\, p\, x_1)\} . \quad (11)$$

Let the path expression ${}^{\circ}p$ be the subset of all paths in $\mathcal{G}$ that have p as its first predicate.

$${}^{\circ}p = {}^{>}p \cup {}^{<}p . \quad (12)$$

The path elements in (9) to (12) can be chained to specify a subset of paths that follow any specific pattern. For example, the path expression ${}^{=}s\,{}^{>}p$ is the subset of all paths from (9) that begin with subject $s$ and predicate $p$ (i.e., all paths beginning from a vertex $s$ and an outgoing edge with label $p$) to any vertices.

$${}^{=}s\,{}^{>}p = \{P \mid x_0 = s \land {}^{>}e_0 = p\} . \quad (13)$$

The expression ${}^{=}s\,{}^{>}p\,{}^{>}q$ is the subset of all paths from (13) that have a successor predicate $q$.

$${}^{=}s\,{}^{>}p\,{}^{>}q = \{P \mid x_0 = s \land {}^{>}e_0 = p \land {}^{>}e_1 = q\} .$$

The expression ${}^{=}s\,{}^{>}p\,{}^{=}o$ represents the set of all paths beginning with the subject $s$ and having an outgoing predicate $p$ and an incoming object $o$.

$${}^{=}s\,{}^{>}p\,{}^{=}o = \{P \mid x_0 = s \land {}^{>}e_0 = p \land x_1 = o\} .$$

Let the path expression $\pi_0\{\pi_1, \pi_2\}\pi_3$ represent a branched path which splits after $\pi_0$ into as many branches as the number terms within the braces where $\pi_i$ represents a chain of path expressions defined in

(9) to (12). This notation may be nested, enabling us to specify arbitrary branching.

$$\pi_0\{\pi_1,\pi_2\}\pi_3 = \pi_0\{\pi_1\pi_3,\pi_2\pi_3\} = \{\pi_0\pi_1\pi_3,\pi_0\pi_2\pi_3\}\,,$$
$$\pi_0\{\pi_1,\pi_2\}\pi_3 = \pi_0\pi_1\pi_3 \wedge \pi_0\pi_2\pi_3\,. \quad (14)$$

For example,

$$^{=}s\,\{^{>}p,\,^{>}q\} = \,^{=}s\,^{>}p \wedge \,^{=}s\,^{>}q\,.$$
$$^{=}s\,^{\circ}\{p,q\} = \,^{=}s\,^{\circ}p \wedge \,^{=}s\,^{\circ}q\,.$$

## 2.4 Contextual Goals

Defining how the system behaves in a given context is key to context sensitive computing. This context-specific behaviour can be modeled as a set of goals. Goals are composed of constraints and actions. In a general graph, especially one as large as the IoT, there could be billions of entities and some of the more complex entities such as power plants may have thousands of goals per entity. In an environment where multiple entities interact, prioritizing goals to evaluate can be a complex problem. An entity needs to quickly prioritize goals to evaluate. Mapping the common context from Definition 2 to a set of goals would ensure that goals in the common context are given priority.

In our example below, goals relating to `California Plant 3` and `Repair Process` are prioritized and can be obtained by a simple lookup.

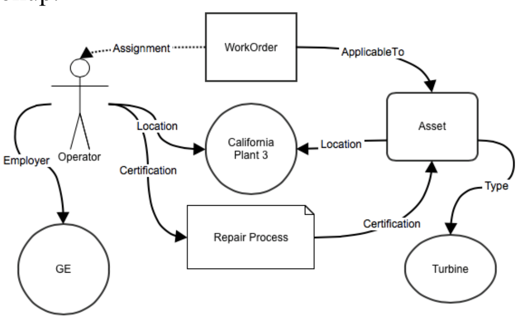


Figure 1: Portion of graph of entities and their known relationships.

Figure 1 represents a small portion of the graph that's relevant to a specific goal, the assignment of a work-order to a qualified operator. The Assignment link from WorkOrder to the operator does not yet exist; adding it is the goal of this exercise.

From our definitions, we have:

Operator's context, from (4):

```
Location: California Plant 3
Certification: Repair Process
Employer: GE
Type: Operator
```

Asset's context, from (4):

```
Location: California Plant 3
Certification: Repair Process
applicableTo: WorkOrder
Type: Turbine
```

Common context for the Operator and Asset Interaction, from (5):

```
California Plant 3
Repair Process
```

## 2.5 Contextual Constraints

Constraints define when a goal is applicable and are specified as a set of paths. If all constraint paths specified by the goal exist, then the goal can be evaluated.

Let $\varphi$ be the path expression that represents a contextual constraint as in Section 2.3

$$\varphi = \pi_0\pi_1 \ldots \pi_k\,. \quad (15)$$

$\varphi$ is said to exist when it contains at least one path satisfying $\varphi$. For a branched path as in (14), all branches should exist.

*Example Contextual Constraint 1:* Only an operator present in the same location should service Asset.

$$Asset^{>}location\,^{<}location\,^{>}type\,^{=}operator$$

Decomposing the path expression above by its constituents, the initial term $Asset^{>}location$ represent the location of Asset, the succeeding term $^{<}location$ represents all entities that are in the same location as Asset and the final term $^{>}type\,^{=}operator$ limits the above to our contextual goal of all operators in the same location as Asset.

*Example Contextual Constraint 2:* Only an Operator who is a GE employee and is certified in the relevant repair process should service Turbines.

$$Turbine\,^{<}type\,^{\circ}certification\,^{\circ}\{type\,^{=}operator,\; employer\,^{=}GE\}$$

This path expression uses the direction agnostic operator from (12) and branching from (14)

## 2.6 Contextual Actions

Actions are simply graph changes such as new arcs added to the graph. These added arcs grow the context and are the elemental constituents of the emerging context.

A contextual action Γ specifies the exact paths to subject and object and supplies the predicate used to insert or remove an arc into the context graph.

Let $\prod$ represent the union of all contextual constraints $\varphi_0$ to $\varphi_k$

$$\prod = \varphi_0 \cup \varphi_1 \cup \ldots \cup \varphi_k \;. \quad (16)$$

Let $\Gamma_{\prod}$ be the contextual action where $\mathrm{p}_\Gamma$ represents the predicate to be added and $\varphi_s$ and $\varphi_o$ represent the path to the subject and object within $\prod$

$$\Gamma_{\prod} = (\varphi_s, \mathrm{p}_\Gamma, \varphi_o) \;. \quad (17)$$

*Example Contextual Action:* Assign WorkOrder to Operator.

$$\Gamma_{\prod} = (Asset^{<}applicableTo, Assignment \; Asset^{>}location^{<}location) \;. \quad (18)$$

In the above:
Subject path: $Asset^{<}applicableTo$
Predicate: $Assignment$
Object path: $Asset^{>}location^{<}location$

From figure 1, its clear that both constraint paths exist in $\mathcal{G}$ and therefore the action can be performed. The new arc can be inserted at the location specified in (18). If multiple matches are found, then the system may simply pick one. If none are found, the operation may not be performed or be deferred to a human.

# 3 APPLICATIONS

We believe that the technique above is generally applicable to any software-defined context.

We have shown an example of operator assignment based on discovered context. This can be extended to the context discovery of any interacting entities whose relationships and attributes are modeled as a graph.

Context discovery and modeling in large graphs such as the Internet of things (IoT) poses special challenges (Pereira et al., 2013). The IoT is a very large graph, possibly in the tens or hundreds of billions of entities and quickly finding the context of any entity or between any two entities is critical to scalability.

In addition, many IoT entities are likely to lose connectivity to the Internet but need to interact with other entities that they are connected to on a local or ad-hoc network.

Our approach enables us to emerge context in a decentralized manner by focusing on the context of any interacting entities and deal with the challenge of huge graphs by reducing the context to a small subgraph as described in section 2.

Entities can maintain a graph model of their attributes and relationships and let the context emerge naturally over their lifetime. This enables them to act independently without the need for a central repository that aggregates and serves as the authority for context of billions of entities.

# 4 RELATED WORK

Goals in the IoT and the Industrial Internet space are related to events. Detecting events in real time is another major challenge for context-aware frameworks in the IoT paradigm (Pereira et. al, 2013). The graph of entities and their relations is continuously and dynamically updated as the users of the system interact with the graph triggered by sensor events or time-based events.

Nguyen et. al. address this challenge using a context-aware framework that uses a form of context graph. They introduce the notion of a graph made of context nodes and action nodes: 'the basic idea of contextual graph relies on the fact that past contexts can be remembered and adapted to solve the current context. The context is managed to organize in the graph type. In the contextual graph, rather than creating a solution from scratch, the contexts similar to the current context are retrieved from memory. The best match is selected and adapted to fit the current context based on the differences and similarities between the two contexts.' (Nguyen et. al., 2008.)

Their approach is also focused on the paths going through a node to discover context. We improve upon Nguyen et al. by further constraining the model by introducing the definitions of context goal, constraints, and common context.

## 5 CONCLUSIONS AND FUTURE WORK

No single system yet exists that could fully satisfy the criteria and challenges for the context-aware requirements for any large system of interconnected entities, especially one on the scale of IoT. The inherent complexity requires more dynamic approach that emerges from the system interactions as the system evolves rather than being pre-calculated. We believe that our graph approach to emergent context gets us closer to the larger goal of a complete contextual system for the Internet of Things.

Our approach can be generalized by extending Definition 1 to context from one to the nth degree, enabling a much larger graph and more indirect constraints and goals.

We could also extend the approach to interaction of multiple entities by extending Definition 2 from two to n entities.

Although Definition 3 implies an archived historical record of every link ever formed and dissolved, we only use the current state of the graph in this paper. The ability to use historical arcs could open new possibilities such as affinity discovery.

GE Software is currently investigating methods connected to this paper's contributions on a broad class of complex industrial and IoT applications such as analytics on large asset graphs.

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# Toward a Holistic Method for Regulatory Change Management

Sagar Sunkle and Vinay Kulkarni
*Tata Consultancy Services Research, 54B Hadapsar Industrial Estate, Pune 411028, India*
{*sagar.sunkle,vinay.vkulkarni@tcs.com*}

Keywords: Regulatory Change Management, GRC, Formal Compliance Checking, Norm Change, Business Process Change Propagation, Risk Modeling.

Abstract: Complexity of regulatory compliance is heightened for modern enterprises due their global footprints and multiple regulations they are subjected to across varied domains and geographies and continual changes therein. This necessitates a method for compliance management that is capable of establishing compliance to both regulations and changes to regulations from a holistic perspective of governance, risk, and compliance (GRC). We propose such a method using a conceptual model of integrated GRC whereby formal compliance checking and norm change techniques for regulations represented as formal rules are coupled with business process change propagation and risk modeling. The method also considers legal and business goals of regulators and regulatees respectively in enacting compliance to regulation and changes therein. The method is substantiated with a brief example of a real world banking regulation.

## 1 INTRODUCTION

Modern enterprises need to comply with multiple domain- and geography-specific regulations. Non-compliance results not only in putting the hard earned reputation of enterprises at stake, but may also lead to personal liability and risk for board directors and top management (Alberth et al., 2012). The compliance problem is acerbated by continual changes to regulations (French Caldwell, 2013; English and Hammond, 2014). Enterprises not only have to be compliant with multiple regulations but also *remain compliant as these regulations change*. Regulatory change management therefore assumes a very important role in any regulatory compliance framework and practices. Proper regulatory change management requires adoption of right attitude at the top management level and machinery to enact compliance to both regulations and changes to regulations.

Interestingly, both industrial governance, risk, and compliance (GRC) solutions and formal compliance checking techniques address the problem of compliance to regulations and regulatory changes in such a way that a compliance solution that is better than both can be obtained by combining the best features from both. Industrial GRC solutions mostly provide informal, content management-based, document-driven, and expert-dependent ways of solving the compliance problem (French Caldwell, 2013), but at the same time support an integrated view of G, R, and C tools and practices, which is a desirable feature since changes in regulations affect aspects of governance and risk as much as they affect already compliant processes (Racz et al., 2011). An integrated GRC solution can help in managing and evaluating assumptions in the current business model and assessing the effectiveness of strategies for new business models (Switzer et al., 2013). Formal compliance checking techniques, in comparison to industry GRC solutions, provide formal guarantees of compliance and several formal compliance analysis possibilities (Becker et al., 2012). But research in formal compliance checking, although extensive, has focused on segments of topics such as compliance checking of business process, changes to legal norms, business process change, and risk modeling without providing techniques from an integrated GRC perspective (Neiger et al., 2006; Schäfer et al., 2011).

In this position paper, we propose to relate formal norm change techniques based on formal compliance checking techniques with business process change propagation and risk modeling based on an integrated GRC perspective. To elaborate our approach, we use elements from a conceptual model for integrated GRC (Vicente and da Silva, 2011). Starting with key elements, we show how G, R, C concerns are treated separately as far as formal compliance checking techniques are considered and eventually we arrive at a method which ensures that all three concerns are addressed while using these techniques. We believe that this method has the potential to provide formal guarantees and analysis benefits along with holistic treatment of G, R, and C concerns.

The paper is arranged as follows. In Section 2, we begin with a conceptual model of GRC and motivate why G, R, C concerns need to be addressed together, and how the current formal research techniques treat these in a divided manner. In Section 3, first we review norm change techniques, business process change propagation in connection with norm change, and risk modeling techniques in that sequence. We then put forth a method for a formal treatment of regulatory changes on top of integrated GRC model. In Section 4 present a very brief example of how this method may be applied to a Know Your Customer (KYC) regulation of Reserve Bank of India (RBI). We discuss some pertinent pointers with regards using integrated GRC perspective for cost-effective enterprise decision making in Section 5 and Section 6 concludes the paper.

## 2 THREE DIMENSIONS OF REGULATORY CHANGE

GRC is an integrated, holistic approach to organization-wide governance, risk and compliance (Racz et al., 2010). Taking the stance that different enterprises would define GRC in their own way, (Vicente and da Silva, 2011) came up with a conceptual model to define the domain of of integrated GRC. We illustrate an adapted version of this model in Figure 1.

Note that Figure 1 deliberately includes elements common to G, R, and C, namely Key Objectives, Policies, Internal Controls, Processes, and Risks. Additionally it contains elements specific to C, namely Regulations and Standards, and elements specific to R, namely Inquires/Surveys, Risk Appetite, Issues, and Heat Maps. *Governance* is responsible for *risk* and *compliance* oversight, as well as evaluating performance against enterprise's Key Objectives. Compliant enterprises need an effective approach to verify that they are in conformity with rules set from external Regulations and Standards and internal Policies which are eventually related to and are exercised in terms of Internal Controls. Enterprise's Key Objectives are achieved by Processes which have an associated set of Risks. Internal Controls should be implemented on top of Processes such that they are able to *track, prevent, detect, and correct* Risks associated with Processes and thereby *fulfill* Key Objectives of the enterprise.

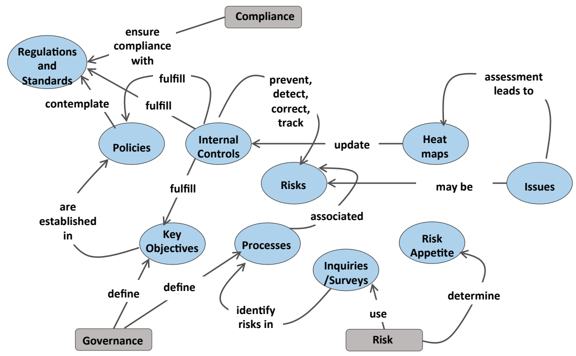


Figure 1: Integrated GRC conceptual model adapted from (Vicente and da Silva, 2011).

Figure 1 represents integrated GRC without differentiating between compliance to Regulations and Standards and compliance to *changes in* Regulations and Standards. The elements related to R not covered in the reading above indicate essentially the industrial GRC way of risk-adjusted decision making in compliance to both regulations and changes to regulations. Based on predetermined Risk Appetite, Risks associated with Processes are identified by expert Inquiries/Surveys. Certain issues with Internal Controls may also be treated as Risks. Based on Inquiries/Surveys, risk Heat Maps are created pointing to specific Processes and business functions and Internal Controls are updated based on evaluation of Heat Maps.

In contrast to industry GRC solutions, formal compliance checking approaches help in reducing the burden on experts by using formal models of regulations and business processes. An extensive research exists in formal compliance checking of regulations where methods to check formalized models of business processes against models of regulations are explicated (Sadiq et al., 2007; Liu et al., 2007; Ly et al., 2010). Additionally, some of these approaches even enable formal proofs of (non-)compliance by utilizing diagnostic information about process activities (Antoniou et al., 2008; Governatori et al., 2009). But research on formal compliance checking of *changes* in regulations is not yet coordinated. This is illustrated in Figure 2.

Figure 2 adds *changes* to key elements of Figure 1 and positions research in formal methods of norm change, business process change propagation and risks associated with changes on top of these elements. It can be seen that links between the common elements of GRC, namely Processes, Internal Controls, and Risks do not hold as illustrated by relations between elements drawn in red. Some relations are

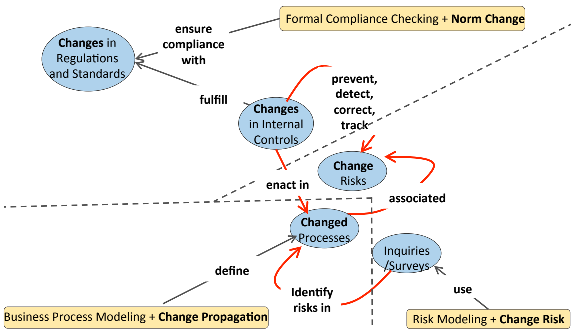


Figure 2: Research on changes in norms, business process, and risks.

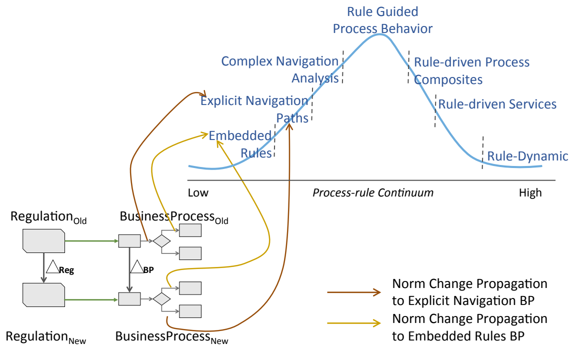


Figure 3: Propagating norm changes to processes.

different from Figure 1, because they depict the way *formal* techniques solve individual problems of norm change, business process change, and change risks. For an effective and efficient regulatory change management, elements in the three dimensions of norm change, business process change, and change risks need to be coordinated. They can be coordinated precisely by focusing on relations drawn in red. We elaborate this in the next section by reviewing existing work in each of these dimensions and then proposing a method for coordination.

## 3 TOWARD A METHOD FOR REGULATORY CHANGE

**Norm Change** Norm change research focuses on different ways in which contraction, expansion, and revision of legal theories can be achieved. Several interesting aspects have to be taken into consideration to formally model norm changes as enumerated below:

1. Distinction between *legal* (obligations, prohibitions and permissions) and *counts-as* rules
2. Distinction between norms and their legal effects and the notion of *defeasiblity*
3. Distinction between *Ex Tunc* and *Ex Nunc* norms
4. Ways in which expansion and contraction of legal effects is achieved
5. *Interpretation* mechanism for balancing goals of norms and legal effects

Each aspect above is elaborated further below.

While legal rules specify the ideal behavior and can be changed by the legislative system such as a regulatory body, the *counts-as* rules provide definitions of institutional concepts. The applicability conditions of legal rules refer to these institutional concepts, rather than to the so called brute facts (Boella et al., 2009).

Considerable research in norm change uses extensions of defeasible logic (Governatori and Rotolo, 2008a; Governatori and Rotolo, 2008b; Boella et al., 2009) and is based on formal compliance checking techniques using the same extensions of defeasible logic (Antoniou et al., 2008) with at least two implementations, namely Formal Contract Language (Sadiq et al., 2007) and DR-Prolog (Antoniou et al., 2008). The notion of *defeasibility* helps in terms of revising legal effects without necessarily revising norms. In other words, obligations can change with normative system being the same, as for instance, due to change in the world, new obligations can be attached or old obligations can be detached from the legal norms. The norms themselves can be distinguished as *Ex Tunc* or *Ex Nunc* based on how the legal effects are realized.

*Ex Tunc* norm is a norm that retroactively changes the legal effects of actions committed prior to the existence of the norm, whereas an *Ex Nunc* norm affects only actions committed after the existence of the norm.

Based on the notions of *Ex Tunc* and *Ex Nunc* norms expansion can be prospective and retroactive promulgation (Gómez-Sebastià et al., 2012) and contraction can be annulment or abrogation respectively. Since regulations are represented as rules in the implementation, different ways have been suggested to expand and contract legal effects such as adding or removing rules, adding exception via defeaters, i.e., rules that can be used for defeating conclusions[1], or changing rule superiority.

Finally, the *interpretation* mechanism enables adapting norms after their creation to the unforeseen situations in order to achieve the social goals they have been planned for (Boella et al., 2009).

The research in norm change does not propose how to propagate changes with regards legal effects realized as modified rule base to processes. We re-

[1]For the formal specification of defeasible logic, its extensions, and proof theory, reader is requested to refer to (Antoniou et al., 2008; Boella et al., 2009).

view the research in business process change propagation in order to suggest a way to do so.

**Business Process Change Propagation** We focus on the fact that industry GRC solutions as well various formal compliance checking techniques enact regulations in processes in terms of rules. The way rules are integrated into business processes may depend on where the default level of rule and process integration in given enterprise lies along what is called as *process-rule continuum* (Sinur, 2009; Koehler, 2011). This is illustrated in Figure 3 top right.

Seven scenarios with regards how rules are integrated with processes were described in (Sinur, 2009) and later elaborated by (Koehler, 2011). Processes with *embedded rules* encode all process paths into the process without explicit rules and denote processes that do not change frequently. In processes with *explicit navigation rules* explicit rules manage and direct the process routes for each process instance. At the end of the continuum with *fully rule-dynamic* processes, rules dynamically configure processes and rules themselves may change.

On the bottom left of Figure 3, we depict the regulation change scenario. Here, original regulations $\text{Regulation}_{Old}$ with which original business process $\text{BusinessProcess}_{old}$ was compliant with, is changed to $\text{Regulation}_{New}$. The new regulations need to be propagated to the original business process in a compliant manner to yield $\text{BusinessProcess}_{New}$. $\Delta_{Reg}$ captures the change operations in terms of rule addition/removal, defeater addition/removal and rule superiority assertions. $\Delta_{BP}$ is a change sensitive function of $\Delta_{Reg}$ meaning that instead of reapplying new rules from scratch, only changes in rules are reflected into business processes.

For *embedded rules* type of process, the change propagation is most costly since the process has to be redesigned by first finding how rules are implicitly embedded into the processes. The change propagation becomes easier along the continuum, such as for processes of an enterprise that fall between the types of *explicit navigation rules* processes and *complex navigation and analysis*. In processes with *explicit navigation rules*, processes contain business rule tasks that determine when a rule component is executed. This is the most common scenario in enterprises (Koehler, 2011). Variation of this type is where rules are annotated to a task. In that case, to propagate changes in regulations, the changed set of rules may be directly annotated to the original task. Next, we quickly review change risk modeling.

**Change Risk Modeling** As illustrated earlier in Figure 2, a standard process of Inquiries/Surveys of Changed Processes may be carried out to ascertain risks resulting from regulation changes that are now propagated to the business processes. The basic formulation for risk estimation is the probability of the identified event evaluated by its consequence. We believe that by incorporating the computation of goals related with norms and legal effects (Boella et al., 2009) into risk modeling, consequences of events (i.e., legal effects) can be computed with more reliability.

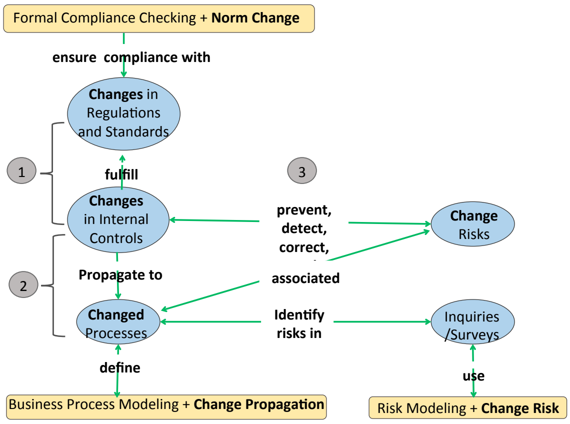

Figure 4: Steps for holistic regulatory change management.

**Method for Regulatory Change** Using formal models of norm change (step 1), changes in regulations can be propagated to business process based on the level of rule integration (step 2) and finally risk can be computed for these changes (step 3). This method is illustrated in Figure 4 by rearranging Figure 2. A possible application of method illustrated in Figure 4 for Know Your Customer (KYC) regulations for Indian banks by Reserve Bank of India (RBI) is briefly described next.

## 4 CASE STUDY

The key goal of KYC regulations is curbing money laundering, and it is achieved by a basic due diligence activity of admitting customers of given type with related set of identity and address documents as specified in several annexes of KYC. Depending on customer types, there may be other due diligence activities that a bank may be obligated to carry out, such as for instance, in case of politically exposed persons or foreign policy investors[2]. In accordance with aspects of norm change specified in Section 3, following can be observed:

1. Definitions of *Customer*, *beneficiary owner*, and

[2]See KYC Master Circular `http://www.rbi.org.in/scripts/BS_ViewMasCirculardetails.aspx?id=9074`

other institutional concepts can be modeled as *counts-as* rules while the due diligence activities for each type of customer can be modeled as *legal* rules.
2. Distinction between norms and legal effects is observable in the regulation change in KYC 2014 from earlier KYC master circulars where introduction of new customer by existing account holders was no longer kept mandatory.
3. While most of KYC regulations are *Ex Nunc*, certain customer types have been introduced, such as foreign policy investors in 2014, and customers matching that profile but admitted in 2013 may be subjected to corresponding regulations *Ex Tunc*.
4. When KYC regulations are implemented as rules (say in DR-Prolog), expansion, contraction, and revision of KYC regulation can be carried out by rule addition/removal, addition of exceptions, and changing rule superiority.
5. Finally, RBI goal of anti money laundering and banks' goal of reducing risk liability while admitting customers across low to high risk profiles could be modeled using goals of norms and legal effects.

The key processes indicated by RBI KYC are new account opening, account transfer, third party transactions, and transaction monitoring. These are the processes to which changes in regulations are propagated. RBI KYC also provides guidelines for risk categorization of customers based on customer types and transaction history which can be used to model risks for specific customers and also changes in risk profiles as regulations change.

# 5 DISCUSSION

**Change Sensitive Propagation** Figure 3 shows that regulatory changes are propagated to business processes. It is less likely but possible that business processes change and now original regulations must be complied with again. In both these cases, propagation should be change sensitive. While we proposed such a way when propagating regulatory changes in terms of rules to business processes, when business processes change, the re-applicability of original regulations to changed processes should be change sensitive as well.
**Enterprise Context** In an earlier work, we showed how to capture enterprise transformation due to various change drivers from as-is to to-be architecture using enterprise architecture (EA), intentional, and system dynamics models (Sunkle et al., 2013). EA models act as descriptive models whereas intentional models and system dynamics models act as prescriptive or decision making models. We also showed how to incorporate directives such as internal policies and external regulations into enterprise to-be architecture (Sunkle et al., 2014). Existing business processes signify current courses of actions that an enterprise uses to achieve its Key Objectives. Since regulations essentially constrain business processes, it may be possible to relate compliance of specific regulations with achievement of specific Key Objectives. Once this interrelatedness is established, it might be possible to model and reason about how to make best decisions.

# 6 CONCLUSION

We have proposed a method that uses formal compliance checking, norm change, business process change propagation, and risk modeling to address regulatory change management with an integrated GRC perspective. We briefly discussed application of this method for compliance with KYC regulations. The integrated view paves way toward balancing achievement of business objectives while complying to regulations taking into consideration risks including those concerning compliance.

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# Enterprise Architecture-Based Service Portfolio Management for Automated Service Catalog Generation

Clemens Landsberg and Markus Esch
*Fraunhofer Institute for Communication, Information Processing and Ergonomics FKIE,*
*Fraunhoferstraße 20, 53343 Wachtberg, Germany*
*itsm@fkie.fraunhofer.de*

Keywords: IT Infrastructure Library, ITIL, Service Portfolio Management, Service Catalog, Enterprise Architecture, EA, Nato Architecture Framework, NAF.

Abstract: IT Service Management (ITSM) tackles the problem of the ever rising complexity of IT solutions by defining small manageable fields of duty with clear responsibilities. The de facto standard in this field is the IT Infrastructure Library (ITIL). One of ITIL's important tools is the Service Portfolio Management (SPM) which aligns the IT to the business and serves as an interface to the customer. Another means for handling complex IT systems are Enterprise Architectures (EA). EA are widely used for strategic planning, documentation and analysis of enterprises in general and IT solutions in particular. This paper proposes an approach that connects EA and ITSM by utilizing EA for SPM. The approach described in this paper enables automated generation of user-group-specific Service Catalogs from EA models. By this means the number of information sources is reduced, which increases the efficiency and reduces the error-proneness of information maintenance. Moreover the reuse of the EA models in the context of SPM is facilitated which aligns both processes and improves the organizational efficiency. The paper presents a proof of concept implementation using the Nato Architecture Framework (NAF).

## 1 INTRODUCTION

The success of an IT service provider is not only based on the product it sells. One of the most common causes for an IT service provider to be unprofitable are wrong decisions in the management. This failures can manifest in a badly controlled infrastructure or wrong business strategies. To address this problem a service strategy is a valuable tool. Forming a well working service strategy is however a very difficult task which requires access to vast IT-, economic- and academic knowledge. The *IT Infrastructure Library (ITIL)* condensates this knowledge in a set of best practices which provide a framework for the management of IT services. This framework divides *IT Service Management (ITSM)* in five phases: *Service Strategy*, *Service Design*, *Service Transition*, *Service Operation* and *Continual Service Improvement (CSI)*. For each phase certain processes are defined that should be implemented by service providers in order to ensure the reliable delivery of their services. As the term 'Service' is highly ambiguous please note that we use the ITIL v3 definition which is: *"A means of delivering value to customers by facilitating outcomes customers want to achieve without the ownership of specific costs and risks."*(ITIL, 2011b). This definition includes both Business Services (a service sold to a customers) and Technical Services (a service that supports a business service).

One of the central processes of Service Strategy is the *Service Portfolio Management (SPM)*. The *Service Portfolio* is the collection of all services of an IT service provider. Each service is described by a service record covering all relevant information about the service such as utility, warranty, management, finances, technology, etc. The Service Portfolio does not only contain the currently available services but also retired and planed services. ITIL uses the Service Portfolio as a tool for strategic decisions on future service development. Each service record needs to include all information needed for such strategic decisions as described in section 3.1. The subset of

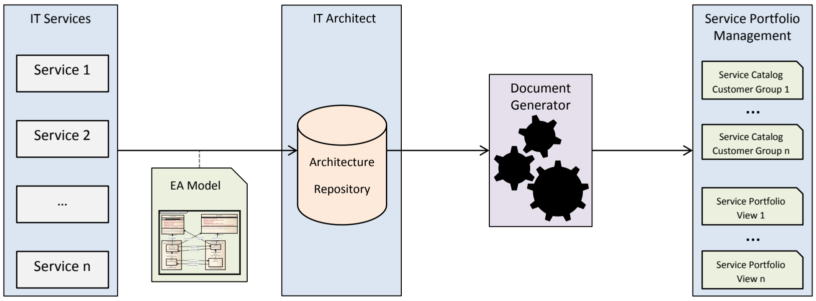


Figure 1: Generating Service Portfolio views and Service Catalogs from EA models.

services which are currently ready for use is the so-called *Service Catalog*. According to ITIL this catalog is maintained by the *Service Catalog Management* process of the *Service Design* phase.

The Service Catalog is made publicly available to customers in order to announce the provided services. ITIL recommends two kinds of customized Service Catalogs: the *Business Service Catalog*, focusing on the utility for the customer and the *Technical Service Catalog*, focusing on the technical details of the service. Often it is beneficial to distinguish even more catalogs, each specifically tailored for a certain customer group or domain. Such domain specific catalogs can focus on the relevant aspects for the given user by composing the catalog accordingly. Typical domains/customers that can be distinguished are business customers, private individuals, technicians, different departments of a company (finances, HR, etc.) or management. Even event-specific catalogs to provide services for some special event are conceivable. A Mobile Service Provider for example may want to create a fancy catalog for private customers. For business customers a serious design is required and certain irrelevant rates can be excluded. Technicians on the other hand need a spec sheet. IT Managers need to see the performance of the Services and the finance department is interested in the Service costs. Maintaining each Catalog separately implies huge efforts and is error-prone. Our approach solves this problem, based on a consistent Enterprise Architecture (EA).

ITIL recommends the use of the EA approach as blueprint for the strategic development of services and to optimize the IT solutions (ITIL, 2011a). EA is an approach to create an abstract model of a whole enterprise, including the processes, the IT infrastructure, the relation to costumers and other enterprises etc. Usually these abstractions are very coarse-grained to allow high level views. The use of EA provides many benefits, Jung summarizes (Jung, 2009) them as follows: *"An organization believes that an EA can help improve the business/IT alignment gap, business and technology communication, and IT project success rate and provide the benefits such as cost reduction & technology standardization, process improvements, and strategic differentiation"*.

To handle the complexity of EA and to give guidelines for the development of such an architecture, several different *Enterprise Architecture Frameworks (EAF)* have been developed. For example *The Open Group Architecture Framework (TOGAF)* or the *Zachman Framework*. Some have been developed for specific domains such as the *Department of Defense Architecture Framework (DoDAF)* or the *NATO Architecture Framework (NAF)*. ITIL does not specify the use of any particular framework but rather focuses on the integration of the EA approach into ITSM processes. For the approach proposed by this paper it is also not relevant which EAF is used, as long as the framework supports the concept of services. Our proof of concept implementation is based on the NAF.

As the name suggests NAF is an EAF used in the NATO environment. The NAF is divided into subviews which describe enterprises in terms of structure, projects, capabilities, business cases, technology, services, and business relationships. While the framework was developed for the defense sector, it may be used in other domains as well since it does not contain defense specific model elements.

SPM as well as EA captures information about the IT services of a service provider. Although both do not require exactly the same set of information there is a huge overlap. For this reason joining SPM and EA is a reasonable approach that bears the potential to rise efficiency and to reduce inconsistency and errorproneness by avoiding duplicated information maintenance. Another advantage is the automated generation of customized Service Catalogs as well as Service Portfolio excerpts for specific purposes and domains.

We propose to capture all relevant information about an IT service in the architecture. SPM tools can acquire this data automatically from the EA and represent it in an appropriate format for SPM. However the primary data source is the EA. In order to allow automated retrieval of the information from the EA strict modeling guidelines are required. Existing

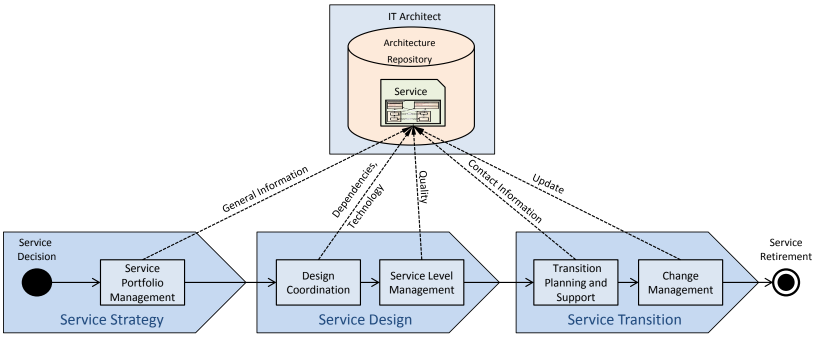


Figure 2: Information are added successively to the EA model during different phases of the *Service Lifecycle*. Changes applied during Service Operation and CSI are induced through the Change Management of the Service Transition phase.

EAF are not specific enough in this point. Hence an extension of the EA meta model is required.

The remainder of this paper is organized as follows: We provide an overview on related work in section 2. Afterward the general approach of *Enterprise Architecture-based Service Portfolio Management* is described in section 3. A prototype realization of the approach is presented in section 4. The paper concludes with a discussion of our main contributions, open issues and future work in section 5.

## 2 RELATED WORKS

The value of EA is undisputed. Ross and Weill examined these benefits and classify EAs in different categories (Ross and Weill, 2006). In their opinion the value is not primarily given by an EA as an usable product. Instead an enterprise applying EAs improves by other means as for example the learning effect yielded by the modeling of the EA. Later research by Ross and Quaadgras (W.Ross and Quaadgras, 2012) showed that the benefit generated by the use of EA is saturated after a certain amount of effort has been spend for EA. It becomes clear that EA needs to be integrated deeper in the enterprise to derive additional value. Our approach tries to create immediate value by generating a usable product for ITSM.

To produce a usable product becomes even more important when you consider that between 40% (Gartner, 2007) and 66% (Roeleven, 2010) of all EA are predicted to fail and do not deliver any value. Of course preventing general EA failures cannot be guaranteed by our approach. However, the risk of producing an useless EA can be reduced by delivering added value for ITSM.

An EA model is mainly a database for enterprise information. As such it is obvious that a direct value can be produced by making the data available to the stakeholders (IT Managers, Technicians, Customers, etc). This can ether be done by an ad hoc visualization (Roth et al., 2013a)(Roth et al., 2013b) or by preparing a polished document as provided by the approach discussed in this paper.

The Idea to combine EA and SPM is not new. In (Bonham, 2004) architectures are applied for Business-IT alignment. Another approach to combine EA and SPM has been proposed in (Sarno and Herdiyanti, 2010). Sarno and Herdiyanti mapped an *Enterprise Resource Planning* portfolio to EA in order to perform business analysis based on this portfolio. Yet the focus of this work is different since it does not take ITSM and ITIL into account. A more ambitious approach is presented by Lankhorst (Lankhorst et al., 2011). Lankhorst proposes to support Portfolio Lifecycle decisions by predicting the costs based on a suitable EA model and benchmarks data.

SPM is usually done using specialized ITSM software that provides a *Configuration Management System (CMS)* such as *HP Service Manager* (HP, 2015) or *MSM Integrated ITSM Software* (MSM, 2015). These tools are typically independent from the service provider's EA and hence constitute a secondary information source. However first approaches for the integration of EA and CMS are currently developed for commercial ITSM tools as well. Jensen for example describes an approach where *Configuration Management Database (CMDB)* items are synchronized with EA models (Jensen et al., 2009). The approach discussed in this paper represents a viable addition to this development and could be integrated into commercial CMS tools.

## 3 ENTERPRISE ARCHITECTURE-BASED SERVICE PORTFOLIO MANAGEMENT

This section presents the details of our Enterprise Architecture-based Service Portfolio Management approach. The basic idea is to align SPM and EAs in a business in order to raise the efficiency. We are using the EA as exclusive information source to avoid duplicated data management. For this reason, the approach is well applicable by enterprises that have established both SPM as well as EA. The general idea is depicted in Figure 1. All services are described by means of an EA model. The models are aligned by detailed modeling guidelines. These guidelines ensure, that all relevant information is captured by the service models and that the information is modeled equally for all services. All service models are kept in a central repository. At any time current Service Catalogs tailored for specific domains and customer groups can be created using a document generator. Moreover different views on the entire Service Portfolio can be generated for different use cases. Please note, that the remainder of this paper focuses on generating tailored Service Catalogs. However, generating Service Portfolio views can be done in an equivalent way.

A detailed description of our approach is provided in the subsequent sections. Subsection 3.1 describes the service record which is the set of all relevant information for a service. Afterwards subsection 3.2 presents an service architecture management process that coordinates the development of the service model during the realization of the IT service. In order to be able to model all the required information on a service the EA meta model needs to be extended as described in subsection 3.3.

## 3.1 Service Record

A service record is the set of all relevant information on a given service. In order to allow informed strategic decisions on the one hand and to give customers detailed information on the provided services on the other hand, a service record needs to contain various information. This includes aspects of finances, user satisfaction, technology, quality, service levels, service dependencies etc. For the purpose of automatically generating a Service Catalog, the minimum set of information contained in a service record is the information provided to customers. To explain our approach we are using an excerpt of this information displayed in Table 1 throughout this paper.

A name or identifier is needed to refer to the service. A service also needs a description. Sometimes it is advantageous to have more then one description, one for each Service Portfolio view and Service Catalog. A classification is often used for a better understanding and to improve searchability. A service record usually contains various contact information. This contact information serves as a reference to all related ITSM functions. Furthermore a service record has to refer to the *Service Level Agreement (SLA)*. As a service can have different variations or different implementations, the SLA specifies the actual service quality as provided by the enterprise.

Table 1: An excerpt of the information contained in a typical service record of a Service Catalog.

| Entry | Explanation |
|---|---|
| Name | Name / identifier of the service. |
| Description | A description of the service. |
| Classification | A classification of the service. For example if it is internal or external facing. Often done by means of a taxonomy. |
| Contact | Reference to important organizational units. E.g. Service Owner, User Help Desk... |
| Dependencies | The composition of the service: Which services are using the service and which services are used. |
| SLA | References to Service Level Agreement (SLA) or Operational Level Agreement (OLA). The SLA is a detailed contract describing the utility and warranty of the service. |

## 3.2 Process Description

In order to implement our approach efficiently it is crucial to define a process for the management of the IT service model. This process needs to interweave the creation of the service model with the processes of the ITSM. Although ITIL defines the IT architect as an organizational unit responsible for the design, creation and maintenance of EA models, it does not specify how EA models are handled.

The process for the creation of the service model is depicted in Figure 2. Responsible for the service model is the *IT Architect*. The life cycle of a new service begins with a strategic decision in the Service Strategy phase. At this point a new, empty service model will be created. During the *Design and Transition* process the service is successively enhanced by additional information. At the first stage in the SPM general information about the service such as name and classification is already available and can be added to the model. The remaining information is not yet available and will be added to the model later on. During the *Service Design* phase the service is planed and designed in detail including technological specifications and dependencies to other services. This information is also added to the service model.

The *Service Level Management* is responsible for the determination of service quality parameters and the definition of service levels. These quality information has to be added to the service model as well. Implementation and operation specific information such as contact information is added to the service model during the *Service Transition* phase through the *Planning and Support* process. Finally the service model needs to be update continuously in order to provide up-to-date information about the service. All service changes are controlled by the *Change Management* process. This process is hence responsible for updating the service models during *Service Operation* and *Continuous Service Improvement*. Since the service models are used as primary information source, continuously updating the service models along with quality assurance by the IT Architect is crucial for the success of our approach.

## 3.3 Meta Model

The basic idea of our approach is to retrieve all required information for the creation of a Service Catalog from the EA models of the services. This requires coherent modeling of the services. EAFs such as the NAF were created to provide modeling guidelines and to ensure uniform models. However EAFs are typically not strict enough in order to enforce biunique models. Practical experience shows, that EA models created by different architects can differ significantly although the same EAF is used. Hence additional modeling guidelines and conventions are required for our approach. Since services are logical constructs that abstract from the internal, technical structure such strict modeling guidelines can easily be defined by specifying for each information item exactly how it has to be represented in the model. Additionally naming conventions help to avoid ambiguous naming.

An EAF is based on a meta model which defines the rules and guidelines for the creation of EA models. However EAFs typically do not cover all aspects of ITSM. Hence a biunique mapping of the information required in SPM to elements of the service model is often not possible. For this reason the meta model needs to be extended by specific entries required in the context of SPM. Extensions are basically additional tagged values and associations between stereotyped classes. For our prototype, we extended the NAF accordingly. Our extensions will be discussed in section 4.1. Based on the extended meta model we were able to define strict modeling guidelines on how to model all the relevant information of a service.

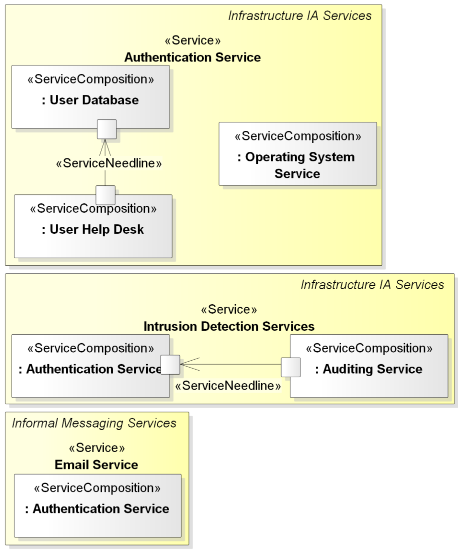


Figure 3: This diagram shows a NOV-6. NAF uses a directed composition relationship with parts to represent dependencies between services. The figure shows on the left hand side on which services the Authentication Service depends. On the right hand side two services are shown that require the Authentication Service.

# 4 PROTOTYPE IMPLEMENTATION

We have realized the approach presented in section 3 prototypically in order to show the approach's viability. For this purpose we have extended the NAF meta model and modeled an example IT service (see subsection 4.1). Additionally a document generator has been implemented that can be used to automatically generate a customer facing Service Catalog from this model (see subsection 4.2). The prototype implementation as well as the modeling has been done using the *Enterprise Architect* of *Sparx Systems* (SparxSystems, 2014).

## 4.1 Example Model

Automatically generating a Service Catalog for the EA model requires that all relevant information is contained in the model. As described in section 3.3 this requires an extension of the meta model by tagged values and associations. We have extended the meta model of the NAF and modeled an *Authentication Service* as an example.

The main element for services in NAF is the stereotype *Service*. Each service is supposed to be represented by a class with this stereotype. As shown in Figure 4 we have extended the Service stereotype

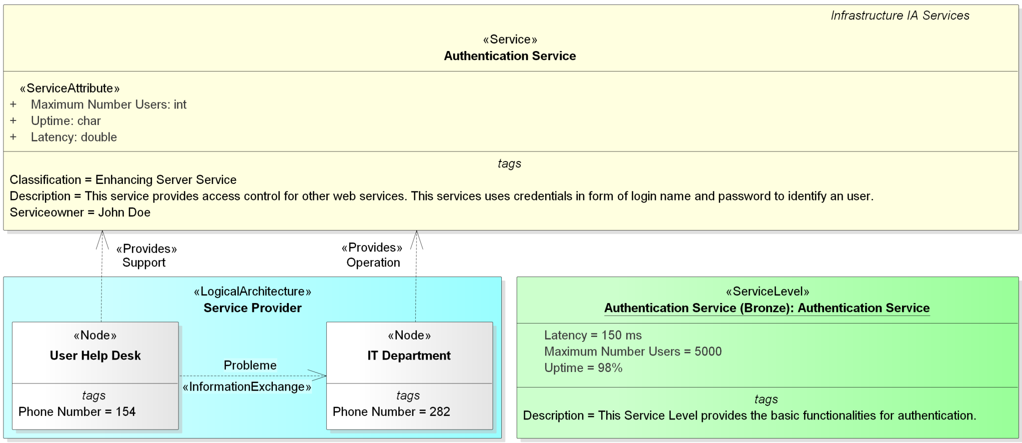


Figure 4: This diagram shows a NOV-2. This view focus on relationships between logical entities. Note that the *ServiceLevel* is not part of a NOV-2 diagram but has been added for illustration reasons.

by additional tagged values. These contain the information required for the Service Catalog. For example the information items *Description* and *Classification* from Table 1 are represented in additional tagged values. Another classification is done by a class hierarchy where each service extents a class from a taxonomy. As shown in Figure 4 the Authentication Service extends the *Infrastructure IA Service* from the *NATO C3 Classification Taxonomy*. The contact information is represented by a *Provides* dependency of the *NATO Operational View 2 (NOV-2)* as also shown in Figure 4. By this means the service is connected to organizational resources.

Using a *NATO Service Oriented View 6 (NSOV-6)*, as shown in Figure 3, dependencies to other services can be modeled using the composition mechanism. The *Utility* and *Warranty* parameters of a service, which are a fundamental parts of the SLA, are defined within the *ServiceAttribute* of the *NATO Service Oriented View 1 (NSOV-1)*. For illustration reasons these attributes are depicted in the NOV-2, shown in Figure 4 as well. The actual service level is expressed by the *ServiceLevel* stereotype and is linked to a particular service provider via tagged value of the *«Provides»Operation* dependency, also depicted in Figure 4.

## 4.2 Document Generator

The purpose of the document generator is to create a human readable document describing the service. The document has to contain the important information of the service in a mixture of text and tables. EA tools typically have features for document generation. They are sufficient for internal use, but reach there limits when a highly polished customer facing Service Catalog or a non sequential processing is required. This requires a sophisticated document generator.

We have implemented an document generator for the Sparx Systems Enterprise Architect. As most EA software this tool provides a build-in scripting runtime environment. It allows us to use internal mechanisms for extracting values from the model, graph traversal and SQL queries on the underlying database. The document generator is a script that reads the information from the EA model and successively creates the output document. For this purpose it uses an *Component Object Model (COM)* API to control an external word processing tool (*MS Office*). Whenever a data item from the model is needed, a subroutine is called that retrieves the desired information. This information will then be written in a document via the COM-API. This process is depicted in Figure 5.

To realize the idea of a customizable Service Catalogs for different domains it was necessary that each subroutine retrieves one atomic unit of information and embeds it into the output document. Document generator scripts for customized Service Catalogs can now easily be created using these subroutines and arranging them as desired. While our prototype implementation still requires writing a document generator script, the process can easily be facilitated by a wizard software. Such a software allows selecting and arranging the information items via a GUI and automatically produces the desired catalog.

# 5 CONCLUSION

The approach presented in this paper combines ITSM and EA. The aim is to improve the benefit of EA for an IT service provider. Moreover organizational efficiency can be improved and error-proneness can be reduced by maintaining just one primary information

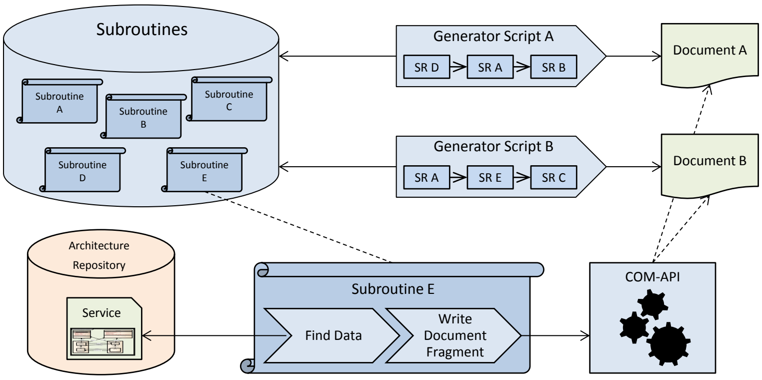


Figure 5: Schematic overview of the document generation.

source. Our approach allows automated generation of up-to-date Service Catalogs and Service Portfolio views tailored for different customer groups, domains and purposes. Moreover strict modeling guidelines for the creation of service models leads to clearly structured models and improves comparability, reproducibility and quality. Finally this entails a speedup of the modeling process since architects can stick to the predefined guidelines.

To show the viability of our approach we presented a proof of concept implementation based on the NAF and Sparx Systems Enterprise Architect. This implementation covers the entire process chain from the architecture model through the document generator to the domain specific Service Catalog.

While we have implemented our approach just for the automated generation of a Service Catalog, an adapter that automatically synchronizes the information from the EA model with a sophisticated SPM tool can easily be realized (Hauder et al., 2013). The implementation of such an adapter is part of our future work in order to show the usability of our approach for the entire Service Portfolio process. Moreover an even deeper integration of EA into ITSM is conceivable by automatically generating up-to-date self-service web pages from the EA model and enabling customers to order the provided services immediately via the web interface.

Another aspect for future work is the improvement of the usability. We are considering a tool that allows non-architects to enter most of the required information about a service in a template or wizard dialog. This information can then be used to generate a service model fragment that constitutes the basis for further modeling by an experienced architect.

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# Simulation-Based Evaluation of Recommendation Algorithms Assisting Business Process Modeling

Adam Styperek, Michal Ciesielczyk, Pawel Misiorek and Andrzej Szwabe
*Institute of Control and Information Technology, Poznan University of Technology*
*Piotrowo 3, 60-965 Poznan, Poland*
{*adam.styperek, michal.ciesielczyk, pawel.misiorek, andrzej.szwabe*}*@put.poznan.pl*

Keywords: BPMN, recommendation systems, process modeling support, usability of process design tools.

Abstract: In this paper, we propose a methodology for objective and repeatable simulation-based evaluation of recommendation algorithms supporting the process of designing of a BPMN model. According to the methodology, an evaluation of the usability of recommendations is done entirely with the use of the dedicated software coupled by a predefined test set. In order to confirm the reliability of the methodology, an additional evaluation based on the user study has been performed.

## 1 INTRODUCTION

Business process modeling (BPM) is considered as an error-prone and time-consuming task (Hornung et al., 2009; Smirnov et al., 2010). Moreover, despite rapid development of BPM technology its users include mostly large companies or organizations. This is due to the fact that, for small and medium enterprises (SMEs), the development of their own systems business process management is still considered too expensive. As a result, there is often a lack of documentation of existing business processes within SME, and even although employees acquire this knowledge, it is not properly formalized.

Modeling a business process may be easier – and thus less expensive – when the user is provided with a tool able to recommend the subsequent step of the process being modeled. For that reason, in the last few years scientists have conducted research on recommendation systems used in business process modeling (Hornung et al., 2009; Koschmider et al., 2011; Hornung et al., 2008). The main purpose of this effort is to provide the user with a tool, that makes the modeling process less error-prone, as a result of using the recommendations of Business Process Model and Notation (BPMN) components based on a repository of already approved BPMN processes. The application of a recommendation system should also make the modeling process less time laborious, thanks to the ability of reusing the parts of the existing business processes in the repository

In this paper, we propose a methodology aimed at providing means for a quantitative and unambiguous evaluation of the usability of recommendation algorithms enhancing software for the visual design of business processes. We are focused at taking into account the specific purpose of a tool supporting the design of BPMN models. In particular we have evaluated to what extent a recommendation system is able to support human BPMN modelers at the syntactic level, and how the provided recommendations may be trusted. Thus, the usefulness has been measured in terms of the actual human effort savings, rather than the recommendation quality measures that are typically referred to in the literature on recommendation systems (Herlocker et al., 2004). This is motivated by the fact that reducing the labor costs could contribute to the spread of BPM technologies among SMEs and, by imposing established design patterns, help to improve the overall quality of the business processes modeled by inexperienced modelers.

Although our evaluation methodology uses the number of human-computer interactions as a basis of a performance measure, it also contains the indirect measurement of the quality of recommendation algorithms supporting the design of BPMN models in terms of modeller decision support. If the recommendation of the BPMN component is syntactically correct but incorrect from the perspective of the model semantics, such a recommendation is classified as a wrong one (i.e., as rejected by a modeller). In this scenario, the proposed evaluation methodology assumes that the user has to add manually the correct BPMN component without the help of recommendations what leads to the increase of the interactions number (e.g., mouse clicks and keystrokes). In other words, as it is usually done in each evaluation methodology, in the phase of testing recommendations' correctness, we used only these models, which have been approved by experts. In such a way, the measure that we proposed also reflects the issues of modeling semantic correctness. However, it has to be stressed that our main motivation is to provide the quantitative measure which directly addresses the issues of human effort reduction crucial from the perspective of SMEs. Our goal is to provide the simulation-based evaluation methodology which takes into account the features of the modelling tool, and this way is more reliable than the methodologies based on the measures typically used in the literature on recommendation systems.

The usability-centric evaluation introduced in this paper corresponds to the usability definition formulated in System and Software Quality Requirements and Evaluation (ISO/IEC, 2011) in terms of effectiveness of achieving the specified goals by a user. Specifically, we assume that, by reducing the required amount of human-computer interactions, it is possible to influence the system characteristics such as learnabillity, operability, user error protection and user interface aesthetics which are subcharacteristics of usability defined in (ISO/IEC, 2011). However, it should be noted that, in contrast to (ISO/IEC, 2011), the introduced evaluation does not involve the analysis of opinions about the evaluated system collected from the users. Instead, we propose a strictly defined measure based on user-computer interactions saved as a result of the recommendation system application.

Finally, the proposed evaluation methodology allowed us to formulate two hypotheses:

**Hypothesis 1.** *The use of recommendations reduces the number of actions performed by a user designing the BPMN model in the shortest possible (i.e., the least laborious) way.*

**Hypothesis 2.** *Real users provided with recommendations are able to reduce the number of actions that are necessary to complete the preparation of a BPMN model.*

In order to verify these hypotheses we have conducted a series of experiments in which a dedicated software system has been used to simulate the usage of a BPMN modeler by a human editor.

In Section 2 we present the state of the art in the area of BPMN recommendation systems. Section 3 introduces evaluation methodology, and includes a short description of recommendation system (Subsection 3.3) and data set used in the presented evaluation (Subsection 3.4). In Section 4 we show the results of our experiments. The critical discussion concerning the effectiveness of recommendations in the case of a BPMN modeling task has been provided in Section 5. Section 6 concludes the paper contribution.

## 2 RELATED WORK

Recommendation-based techniques are becoming more and more important in the area of research on business process modeling support methods (Koschmider et al., 2011; Li et al., 2014; Kluza et al., 2013). Authors of (Koschmider et al., 2011) has introduced the business process modeling support solution as a recommendation system and described it as a hybrid recommendation system having features both of content-based recommendation (as a result of processing the data about components' descriptions) and collaborative-based recommendation (as a result of processing the already developed models stored in the repository, which serve as a knowledge base). At the same time, according to (Koschmider et al., 2011; Chan et al., 2011; Zhang and Xu, 2009) the recommendation-based techniques for the business process modeling may be regarded as context-based recommendation systems for which the modeling context is defined by process elements that are already inserted in the workspace.

A few articles presenting recommendation-based techniques for Business Process Modeling (BPM) provide the performance evaluation results (Koschmider et al., 2011) (see Table 1 for comparison). On the other hand, the state-of-the-art solutions use a variety of approaches involving recommendations such as the recommendation of process fragments and process auto-completion (Koschmider et al., 2011; Born et al., 2009; Wieloch et al., 2011), recommendation of subsequent BPM elements during the modeling process (Zhang and Xu, 2009; Zeng et al., 2011) (the approach investigated in this paper), as well as the recommendation of entire processes and component labels (Leopold et al., 2011). Due to variety of recommendation approaches used in this area, the need for defining the common user-centric performance evaluation methodology enabling the fair comparison of proposed solutions appears as even more evident.

Some attempts to adopt information retrieval measures (such as precision and recall) to business process modeling have been made (Dijkman et al., 2011) but they have been limited to the task of process similarity discovery. In the case of the most advanced recommendation solutions (Koschmider et al., 2011; Li et al., 2014; Hornung et al., 2008; Cao et al., 2012; Zhang and Xu, 2009) the set of more user-centric measures has been used, including the number of recommendations used by the modeller, the recommendation accuracy and the reduction of modelling time. However, these measures do not cover all the issues regarded as crucial from the perspective of the system usability. Particularly, they do not reflect the reduction of the number of user-system interactions that are necessary to build the entire model, including the necessary mouse clicks and keystrokes.

From the perspective of user interface usability the research of (Nielsen and Molich, 1990; Wharton et al., 1994) has to be mentioned. In particular, in (Nielsen and Molich, 1990) the authors discuss the major assumptions of user interface design and evaluation process whereas in (Wharton et al., 1994) the interface usability measurement principles are analysed. In contrast, in our paper we do not evaluate the user interface – our goal is to measure the reduction of time and necessary human-computer interactions, when user applies the recommendation system in modeling process.

Table 1 summarizes the comparison of state-of-the-art approaches to providing recommendations supporting business process modeling from the perspective of types of similarity between processes used by recommendation engines, conducting experiments aimed at recommendation quality evaluation, and the use of the ontology-based support for the semantic enhancement of process representations.

Most of the articles referred to in Table 1 contains a recommendation quality evaluation section. In (Li et al., 2014) and (Zhang and Xu, 2009) the systems are evaluated by measuring the computational effectiveness and the accuracy of recommendations for every flow node. The authors of (Dijkman et al., 2011) measure the precision and recall of provided recommendations and compare them with explicit human assessments. In (Minor et al., 2007) the users selected 10 processes from a train set that best match the processes from test set, and subsequently – by comparison with corresponding recommendation lists – the precision was calculated. In (Koschmider et al., 2011) the authors performed experiments in which the users had to model a business process based on its textual description. The semantics, syntactic, structural and labeling correctness of the modeled processes was then verified. Koschmider et al. admit that they did not evaluate yet on how to suggest such recommendations to modelers that would allow them to finish modeling faster. In particular, it has been pointed out – along with integrating the results from the domain of human-computer interaction – as a potential direction for further studies. This paper follows these findings and additionally contributes them by proposing an evaluation methodology enabling to measure the reduction of human-computer interactions while not requiring the participation of real users.

# 3 EVALUATION METHODOLOGY

The experiments have been performed in both the scenarios: with and without the use of a recommendation system. In each of the experiments the simulator has been used to gradually 'design' a given process model (known a priori to the simulator and unknown to the recommendation system) and, in parallel, to evaluate recommendations received after adding each element of the BPMN model being constructed during the experiments. Subsequently, we have performed an additional user study in order to verify the real-world reliability of the automatic evaluation results. It is worth noting that, despite the fact that the verification step required the participation of human users (which may be a potential source of bias or unrepeatability), the methodology may still be considered as objective, as it does not rely on users' opinions but solely on independently measured experimental outcomes.

## 3.1 Assumptions and Measures

According to the proposed evaluation methodology the usability of the recommendation system is measured by estimating the amount of actions a user has to perform in order to place a new BPMN element on the model diagram. Such an amount of actions is estimated by calculating the number of unit operations (see Definition 1) performed by the user. The percentage of operations that the user does not need to perform thanks to the use of recommendations, is used as the quantitative usability measure. Subsequently, the individual scores corresponding to the addition of the BPMN elements are averaged to obtain the overall usability seen from the perspective of designing the entire BPMN model.

**Definition 1.** *The unit operation is assumed to include mouse cursor movements and mouse clicks, required by the BPMN editor to modify the newly added BPMN component (e.g., to change its name or type).*

Table 1: Comparison of solutions aimed at supporting BPM edition.

| | Similarity | | | Evaluation | Ontologies support |
|---|---|---|---|---|---|
| | labels | structures | behavioral | | |
| Minor et al. (Minor et al., 2007) | no | yes | no | yes | no |
| Li et al. (Li et al., 2008) | no | yes | no | no | no |
| Van der Aalst et al. (van der Aalst et al., 2006) | yes | no | yes | no | yes |
| Smirnov et al. (Smirnov et al., 2009) | yes | yes | no | no | no |
| Koschmider et al. (Koschmider et al., 2011) | yes | yes | no | yes | yes |
| Madhusudan et al. (Madhusudan et al., 2004) | yes | yes | no | no | yes |
| Dijkman et al. (Dijkman et al., 2011) | yes | yes | yes | yes | no |
| Li et al. (Li et al., 2014) | no | yes | yes | yes | no |
| Zhang et al. (Zhang and Xu, 2009) | no | yes | no | yes | no |

The number of unit operations (defined as above) required to add each element to the model is equal to 1 when it has to be modified, or 0 when no change is needed.

In order to estimate the effort necessary to type the component name, the additional assumption enabling calculation of the number of keystrokes in terms of unit operations is needed. In (Card et al., 1980), the authors presented a study on the time needed by the users to perform basic actions such as typing and mouse cursor movements or clicks. Based on the presented analysis it has been concluded that, in average, at the same time as performing a unit operation (as defined in Definition 1) the user is able to type in 4, 2, or 1 character, depending on the user's typing skills (135, 90, or 55 keys per minute, respectively). We follow these findings, and we additionally assume that nowadays a typical computer user is able to stroke 135 keys per minute. In other words, we assume that an average user of the evaluated system is able to type in 4 characters and perform a unit operation during a similar unit of time.

Finally, we assume that the usability $r_i$ of the recommendations provided for each element $i$ is calculated using the following formula:

$$r_i = 1 - \frac{a + \frac{b}{w}}{a + \frac{n_i}{w}} = \frac{n_i - b}{wa + n_i}, \tag{1}$$

where:

- $a$ indicates whether a user had to perform a unit operation ($a = 1$) or not ($a = 0$),
- $b$ denotes the number of keystrokes performed by the user during entering the element name,
- $n_i$ denotes the number of characters in the name of $i$-th element of the model (we assume that $n_i$ is greater that 0 and $b \leq n_i$),
- $w$ is the weight which denotes the number of characters that user can type during the same time as one unit operation (in the presented evaluation results we use the weight $w = 4$).

The goal of Eq. 1 is to calculate what part of the operations necessary to add a new component is saved (i.e., does not need to be done manually) as a result of using the recommendation results.

The usability $r$ of the recommendation system experienced by the user designing a given business process model is calculated in accordance with the following formula:

$$r = \frac{\sum_{i=1}^{n} r_i}{n}, \tag{2}$$

where $n$ is the number of elements contained in the model. Specifically, sequentially for each element from the test set a corresponding recommendation list is evaluated. Such a list is generated by the recommendation system, based on the elements that were previously added to the currently designed BPMN model and they descriptions. If the provided recommendations include the currently evaluated BPMN element, values of $a$ and $b$ are set to 0. Thus, according to Eq. 2, it is assumed that the effectiveness of the recommendation system $r_i$ is equal to 1. Otherwise, the number of mouse-related unit operations $a$ is set to 1, and the number of keystrokes $b$ is set to be equal to the number of different characters between the name of the current element and the name of the recommended element having the same type. If the recommendation list does not contain even a partially matched element, $b$ is set to be equal $n_i$. In such a case, $r_i$ is equal to 0, and thus it is also considered as a recommendation system miss. Finally, the BPMN element is added to the current model, and the next element is tested. If the element is the end event, the evaluation is stopped (as there are no more elements to add), and the next BPMN model from the repository is taken for the evaluation.

The evaluation presented herein has been performed using a *leave-one-out* method – which is well known in the Information Retrieval domain, where for each individual test case one of the models is removed from the repository. The remaining models in the repository are then used as a training set for the recommendation system, while the elements from the removed model are used as a test set. Under such conditions, the experiment is performed for each model in the repository.

It has to be stressed that the proposed evaluation methodology does not take into account all the effort saved by the BPMN editor in order to decide which component should be used.

## 3.2 User Study Methodology

In order to verify whether the results of the proposed evaluation are accurate we have proposed to perform a corresponding user study. Such an evaluation, besides the participation of users, requires a BPMN modeler software with an integrated recommendation system. In our study we have used the Activiti Modeler (Activiti, 2014). However, basically any BPMN editor that could be integrated with a recommendation system might be used as well. Figure 1 presents the user interface – the recommendation module is integrated with the BPMN 2.0 shapes repository located on the left side of the screen.

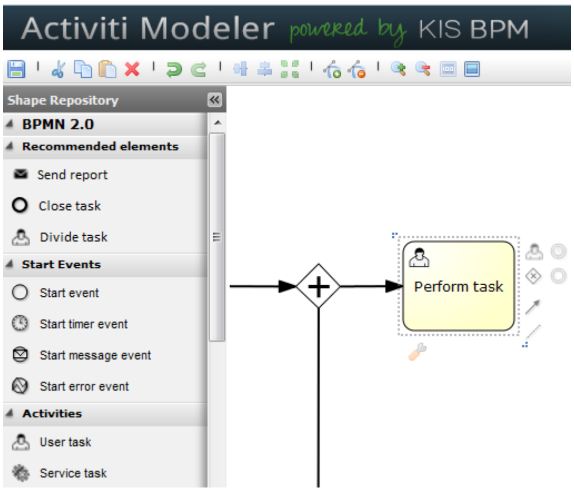


Figure 1: The user interface of the BPMN editor (with the recommendation module on the left).

In order to quantitatively estimate the usability improvement achieved by the employment of a recommendation module into a BPMN editor, we have conducted a randomized experiment with two variants, which are identical except for one variation that might affect a user's behavior. The first variant is a control one and includes an unmodified BPMN editor. The second variant in the controlled experiment involves the additional use of the recommendation system assisting the user. Using such an approach enables to perform a two-sample hypothesis testing.

### 3.2.1 Preliminary Assumptions

The proposed methodology for the user study is based on the following preliminary assumptions:

- The number of tests involving the usage of each of the two variants has to be equal so that the two groups are equally represented. In other words, half of the tests should be performed with the use of the recommendation module, and half of the tests should be performed without it.
- Every user should perform the same number of experiments that involve and do not involve the use of the recommendation module. In such a way we minimize the bias caused by inevitably different modelling abilities of the users.
- The order of the individual experiments for each user must be confirmed to be random. The users, especially those inexperienced ones, may improve their skills during the experiment. Thus, setting up the individual tests in a specific order could potentially favor the experiments performed latterly.
- The business processes to be modelled in the experiment should be equally distributed between the users in order to avoid, as much as possible, the bias introduced by a different level of difficulty of each model.
- Every experiment should be unmoderated. Specifically, the users should have complete freedom on how to perform the assigned tasks.

Specifically, the testing scenario assumes that each user receives a printed diagram of the BPMN process (approved as a correct one by experts) to be modeled using the provided editor. The procedure assumes, that the user has to model exactly the same process as in the printed diagram. Thus, the semantic quality of the process to be modeled is ensured – the user has the knowledge of a correct business process, and the modelling is finished when such a process is obtained. Subsequently, the usability of the recommendation system is estimated using the Eq. 2 – the same as in the case of the simulator described previously. Additionally, we also evaluate other factors important from the perspective of user interface usability such as:

- The time spent on modeling each process,
- The total number of keystrokes, and

- The total number of mouse clicks.

These components have been identified as actions inspected in a formal action analysis in (Holzinger, 2005).

#### 3.2.2 Results Interpretation

The final usability result of the recommendation system (in the range $< 0,1 >$ – the higher, the better) is calculated as the arithmetic average of results obtained for each element. Particularly, if the result is equal to 1 the user made a whole model only with the use of the elements from the recommendation panel and did not have to enter the names (or any other attributes) of the elements. Conversely, if the result is equal to 0 the user either did not use any of the recommended elements or used some but have to changed the whole names of all of them.

### 3.3 Recommendation System

We implemented a recommendation system that supports the user in the usage of a graphical BPMN editor – Activiti (Activiti, 2014). Each query submitted to the recommendation system contains the currently designed business process model and an information about the currently selected element. As a result, the system returns a list of recommendations containing new BPMN elements which semantically match to the current model, and could be effectively added by the user to the diagram. The length of the recommendation list has been set to three elements by default (however, it can be changed by the user).

In order to generate a useful list of recommendations, the system analyses both reference business process models (originating from a process repository) and behavioral patterns (collected during the operation of the system). Both structural information concerning the process flows, BPMN types taxonomy and textual artifacts are used by the recommendation algorithm to provide relevant feedback to the user. All of the information is stored in a common Resource Description Framework (RDF) format compliant with a specifically designed ontology describing BPMN artifacts. Such an approach enables to store heterogeneous data and jointly process it.

Figure 2 presents a conceptual view of the system components. The presentation layer, built within the Activiti, is responsible for capturing all of the relevant user actions and for asynchronous displaying the received recommendations. The service layer module communicates with the recommendation system and acts as a data converter. Specifically, it transforms the data collected by the presentation layer into semantic RDF documents and conversely – the RDF documents received from the recommendation system into the JSON format used natively by Activiti.

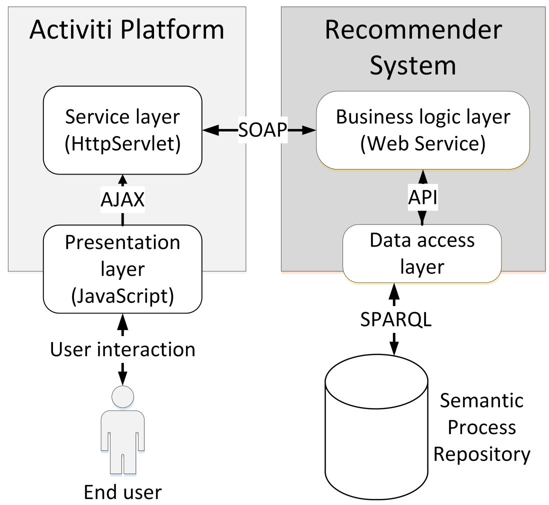


Figure 2: Conceptual view of system's components.

A more detailed description of the implemented software used is clearly out of the scope of the paper, since it is not focused neither on introducing novel recommendation techniques nor on the evaluation of the specific algorithm.

### 3.4 Data Set

The data set used in the experiments presented in this paper has been created as one of the outcomes of the Prosecco project[1] that are not publicly available. This data set includes BPMN models of processes from the field of small and medium enterprises only, what makes it a rather untypical BPM repository. As a result of focusing on this quite specific market sector, the data set is relatively small: it contains only 78 BPMN models and contain 625 distinct elements. The set of models taken into the evaluation includes 858 elements, what gives the average of 11 elements per model (sequence flows were not taken into account). It is worth to note that in most cases, the repository contained no elements from the test set, what made any proper recommendation impossible. This issue has been caused by the insufficient number of similar models stored in the repository. In general, only in the case of 172 recommendation queries (about 2.2 per model) the system had a chance of providing a correct recommendation since

[1] `http://geist.agh.edu.pl/pub:projects:prosecco:start`

for the remaining queries the element needed by the user was not even present in the training set.

# 4 EXPERIMENTAL RESULTS

We performed a series of experiments - each executed in accordance with the evaluation methodology described in Section 3.1. The results of the experiments realized by means of the dedicated software system (logging all of the required parameters), are presented in Table 2. The 'average gain' denotes the average of recommendation usability for all models, calculated as a mean of recommendation usability of each model based on the Eq. 2. The average number of possible recommendations per model is equal to the number of correctly recommended elements divided by the number of elements that could be recommended. The recommendation engine under test has properly recommended 68 elements (what gives the average equal to 0.87 per model). A recommendation is considered as a proper one if and only if the user does not have to change anything in the element, i.e., the recommended element is identical to required element.

Table 2: Evaluation results.

| Measure | Value |
|---|---|
| Average gain from recommendation | 0.10 |
| Correctly recommended elements | 68 |
| Average correctly recommended elements per model | 0.87 |
| Average gain from recommendation, when recommendation was possible | 0,4 |

The conducted evaluation led to the result of 0.10 recommendation usability calculated according to the Eq. 2 what confirms Hypothesis 1. The difference between this score and the value of properly recommended elements per model (equal to 0.87) is a result of the fact that (in accordance with the Eq. 1) the positive values of usability are calculated also for recommended elements that were not identical but only similar to the reference element – i.e., for elements of the proper type, for which the user did not have to delete or type more characters to correct the recommended element name, than in the case of typing the name from the beginning.

It should be noted that, for comparison purposes, we have also evaluated an algorithm yielding random recommendations. Not surprisingly, due to respectively high diversity of BPMN elements in the data set, such an algorithm has not provided any measurable benefit in our experiments – both in terms of the usability and accuracy. Thus, we omit its detailed analysis in our evaluation results.

## 4.1 User Study Results

In parallel to the evaluation done with the use of dedicated simulation software, in order to verify methodology correctness, we have conducted a user study done using the Activiti Modeller tool. The user study consisted of 48 tests. 24 tests have been performed with the support of the recommendation system, whereas the remaining 24 tests without this support. The half of the participating users have been qualified as expert users (with the previous experience in BPMN modelling) when the remaining group as non-expert users (without any or with a very little experience in BPMN). The models taken to this study have been selected on the basis of the results of the evaluation performed with the use of the simulator: the models with the highest values of the recommendation usability have been chosen for the user study in order to enable a more detailed evaluation of recommendation operation, i.e., in order to demonstrate the methodology correctness in the case of applying recommendations. For the models for which the system was not able to suggest the correct recommendation, both the simulation-based and user-performed evaluation provided the same result indicating no reduction of the number of interactions. Table 3 illustrates the results collected during the user study.

Table 3: Average recommendation usability in a test performed on 8 selected models.

| Measure | Simulation | User study |
|---|---|---|
| Recommendation gain | 0.33 | 0.27 |
| Correctly recommended elements | 22 | 18 |
| Correctly recommended elements per model | 2.75 | 2.25 |

For the purposes of the user study, only 8 business process models (out of 78) have been used. Particularly, due to extremely high data sparsity, we have chosen those models for which the tested recommendation system was able to generate the most useful recommendations (thus the average gain resulted in the higher value). By that means we were able to meaningfully measure usability of the recommendation system. Obviously, if the system was not able to provide any useful recommendations due to no relevant data in the training set, such an experiment would be negligible. In order to make the results of our experiments comparable, we also provide the test results of a simulation performed using exactly the same 8 business process models. It should be also stressed that the simulator tool may be considered as an ideal business process designer performing the optimal number of steps required to build a given business process. Thus, as presented in Table 3, the real users, despite the fact that they were in average provided with 22 correct recommendations, used only 18 of them. Nevertheless, this observation confirms that Hypothesis 2 is true. Nonetheless, we may state that our evaluation methodology enables to provide approximately the same result as an analogical user study, without the cost of engaging multiple human testers.

Based on the results from the user study we can also conclude that the tested recommendation system decreases the average number of interactions between the user and a computer. Specifically, in our study, the recommendation system enabled to decrease both the number of mouse clicks by 25% (at a significance level $\alpha = 0.01$) and the number of keystrokes by 22% (at $\alpha = 0.01$). Although such a result slightly differs from the usability measured according to Eq. 1, we may state that the difference between these results is not significant ($\alpha = 0.05$). Although the results of the user study have shown that the recommendation system allowed to slightly decrease the average time spent on modeling every process – by about 4%, the statistical analysis indicated that the difference was not significant ($\alpha = 0.05$). In other words, we have not observed that the recommendation system has any significant influence on the modeling process time.

## 5 DISCUSSION

Business process modeling is considered as highly intellectual work which requires creativity and the knowledge about the modelled domain. Therefore, although recommendation-based techniques are becoming more and more important in the area of research on business process modeling support methods (Koschmider et al., 2011; Li et al., 2014; Kluza et al., 2013), many people have a strong believe that it is not possible to have really useful recommendation solution that helps human modelers in this task. Nevertheless, since many enterprises (including SMEs) has already got a set of approved correct business processes the perspective of reusing their fragments seams to be promising.

In order to help find the answer to the question of recommendations' usability in the area of business process modeling, in this paper, we have defined the evaluation methodology, which involves the application of a quantitative measure which models the human effort reduction considered to be crucial from the perspective of enterprises. Our choice was motivated by the need of objective evaluation which is not based on human opinions. Nevertheless, using such a technical measure may be regarded as not sufficient from the perspective of evaluating the semantic value of recommendations. However, despite the fact that the proposed quantitative measure is rather technical, it also indirectly reflects the issues of the support of human business process modelers at the semantic (pragmatic) level. The reason of this statement is the fact, the evaluation assumes the application of correct (and approved by experts) models when testing recommendations correctness. This way, each semantically incorrect recommendation leads to the performance decrease in terms of the proposed measure based on human-computer interactions. Therefore, the methodology measure evaluates not only the reduction of the number of actions performed by users but also (indirectly) the semantic value of the recommendations.

Finally, it has to be stressed that the goal of presented research was not to propose a new the recommendation algorithm but to provide the simulation-based evaluation methodology which is objective and, at the same time, reflects the features of a BPMN modeling tool (we have chosen the Activity Modeler tool for this purpose).

## 6 CONCLUSIONS

The realism of any evaluation of a recommendation system stays in clear conflict with the objectiveness of the evaluation and with the ability of fully automatic evaluation experiments' execution. In this paper, we present a methodology that is not based on users opinions nor on results of experiments involving human BPMN designers. According to the proposed methodology, an evaluation of the usability of recommendations assisting the process of designing of a BPMN model is done entirely with the use of the dedicated software coupled by a predefined test set. In order to confirm that the realism of the proposed methodology is not significantly compromised by the objectiveness and the repeatability of the proposed methodology, we have accompanied the fully automatic experiments (performed with the use of a simulator) by analogical experiments involving the human users' participation: we have compared the results of the fully repeatable experiments with the results of the more realistic experiments. On the basis of this comparison, we are able to confirm that, at least as far as the use of the Prosecco project BPMN data set is assumed, evaluation experiments performed in accordance with the proposed methodology are both exactly repeatable and able to provide reasonably reliable results.

Based on the comparison of simulation-based evaluation and the user study, one may conclude that the presented methodology provides the correct estimation of the level of human-computer interaction reduction obtained as a result of applying recommendations. The evaluation results have showed that the application of the recommendation system that was used in the presented experiments, decreases the number of human-computer interactions during the BPMN modeling process. Thus, it could reduce the expenses for documenting and optimizing business processes of SMEs, which usually do not posses specialized knowledge of business and information technology frontier. The user study evaluation results confirmed that users provided with recommendation system apply the suggested recommendations, what can improve the reusability of the obtained models or BPMN elements. The results have also confirmed the correctness of both the hypotheses formulated and investigated in this paper.

This paper motivates several potential directions of the further research. So far we have focused on developing a quantitative evaluation methodology. For future work we plan to investigate, using the introduced methodology, advanced recommendation algorithms enabling to process heterogeneous data (including metadata and semantic data) when their data structure may not be known in advance. The most promising solution in this domain are the algorithms based on Statistical Relational Learning methods, which allow modeling of multi-relational structures constructed on the basis of heterogeneous input data and prediction based on these data.

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# Application of a Discrete Event Simulator for Healthcare Processes

Gregory Casier, Koen Casier, Jan Van Ooteghem and Sofie Verbrugge
*Internet Based Communication Networks and Services research group IBCN, Ghent University, Belgium*
*Gregory.Casier@intec.ugent.be, Koen.Casier@intec.ugent.be, Jan.Vanooteghem@intec.ugent.be, Sofie.Verbrugge@intec.ugent.be*

Keywords: Discrete Event Simulator, eHealth, Process Simulation, KPI, Multi-objective optimization.

Abstract: Hospitals are currently catching up with other industries to utilize IT tools for optimizing their patient, data and supply flows. The complexity of the processes and the amount of different resources and specialized personnel make a good view on the costs and effects of changes hard to understand. In light of this growing interest in healthcare towards leaner processes and better performance analytics, a process simulator was being developed. A Discrete Event Simulator (DES) allows the monitoring of Key Performance Indicators (KPIs) over existing processes and reveals opportunities for optimization. Opportunities to improve existing processes can easily be tested to verify possible gains before an actual implementation. Harmful side effects caused by changing the existing process can thus be measured on beforehand. The context in which the DES was being developed and an overview of the tool by explaining its different phases is provided, as well as an indication on potential further research topics and next developments.

## 1 INTRODUCTION

Hospitals consist of a complex set of clinical, material and information flows, which must come together in a point-of-care where the patient and the healthcare professional interact. These patient care processes are complex in nature (Mans et al., 2009) and often very isolated over the different disciplines that are present in a hospital (Lenz et al., 2002). While lean methods have been applied thoroughly in other sectors like car manufacturing, hospitals are lagging behind. The healthcare sector is currently in a lean learning phase to reduce inefficient operations and increase quality of service, but the synchronization of the different flows in an efficient manner is still a huge challenge. (Kim et al., 2006) A more patient oriented workflow, at the same time enabling efficient hospital operation, calls for innovative IT systems.

Several new methodologies are required to support this. One clearly identifiable need is to develop novel solutions for identifying, installing and monitoring an appropriate set of KPIs over the current processes. Process modeling methodologies will allow studying and optimizing process flows. By adding resource consumption information we can simulate, analyze and evaluate the impact of the proposed process optimizations for the chosen operational indicators (e.g. patient safety, quality, cost efficiency). Simulating the proposal before implementing actual processes can avoid a lot of unnecessary costs, especially regarding the complex nature of processes in healthcare. (Bohmer, 2009)

For these reasons, a full discrete event simulator was constructed, capable of simulating a process based on statistical information on patient numbers and inter-arrival time, task timing, choices, etc. The simulator runs as realistically as possible a set of events through the process in which thousands of tasks can be simulated in less than a minute, and gather information on personal, patient and equipment timesheets (when in use or in treatment), waiting times and queue lengths, probabilities of events, etc.

These simulations allow us to monitor predefined KPIs and as such identify opportunities to improve the actual processes. Defining and adopting KPIs in a healthcare organization has proven useful by not only allowing the introduction of modern management approaches, but also by helping to revise the strategy. (Grigoroudis et al., 2012) Consequently, changes that might result in redesigned processes can also be checked on possible side effects before implementation.

Literature indicates different usage possibilities of simulation-based tools in a hospital environment. In (Jacobson et al., 2006) an overview is given of such implementations. A distinction is made between patient flow optimization and analysis and health care asset allocation. Within the patient flow optimization there are several subtopics in which a DES has been applied. These include Outpatient Scheduling, Inpatient Scheduling and Admissions, Emergency Room Simulation Models, Specialist Clinics and Physician and Health Care Staff Scheduling. Also in (Günal and Pidd, 2010) a literature overview of discrete event simulators being applied in healthcare is being provided. The author indicates that the survey demonstrates the specificity of the studies. The simulators built have been found to be mostly unit or facility specific.

The remainder of this paper is organized as follows: first an overview of the iMinds eHealth project HIPS in which context the simulator was constructed is being provided. (HIPS, 2014) Secondly an overview of the DES is given and its different phases are being explained in more detail. Finally, we provide the reader with a general conclusion and make recommendations on further possibilities to extend the provided approach.

# 2 HIPS PROJECT

In this section a short overview of the project in which this simulator was developed is being provided. The HIPS project is an ongoing iMinds research project with both academic and industrial stakeholders in which the synchronization and optimization of different hospital flows is a key goal.

## 2.1 Context

According to the analytics at Gartner (Shaffer, 2012), "Healthcare is catching up with other industries in its demand for more timely and robust performance analytics and dashboarding". Many of the technological aspects are feasible today. But it has yet to become a reality because the healthcare supply chain, from manufacturer to patient, remains fragmented, with limited visibility and interconnection (Ebel et al., 2012).

Within a hospital environment a huge variety of processes and resources can be identified (Figure 1). These processes vary in nature. Processes can often not be planned in advance, and may occur in sequential or iterative mode (Bohmer, 2009). Most importantly, not being able to execute a process in a timely way may have a life threatening impact on the patient whereby the liability of the staff is very high. This makes a hospital environment an extremely complex environment to manage, unlike manufacturing organizations.

The mere size of the hospital has only a minor impact on the variety of processes. It is the number of supported treatments and specializations within a single hospital environment that has a high impact on this diverseness.

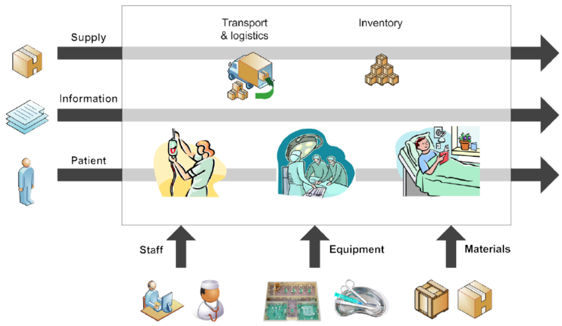


Figure 1: Overview of processes involved (AS IS).

Within this large variety of processes 2 main types of processes can be identified:

- The actual **Treatment** processes aiming to care, cure or help the patient, whereby treatment includes all technical medical and clinical activities related to diagnosis and therapy of illnesses, surgery, palliative care or other care; in a hospitalization mode or in a day treatment mode. This is the fundamental production process and determines how the care is given, and is reflected in a care path.
- The **Supporting** processes that target to serve or to support the treatment of a patient. Supporting processes basically include all non-treatment processes; finance, logistics, human resources, purchasing, etc.

One of the primary goals of the HIPS project is to design a methodology in order to optimize the supporting processes and align them with the treatment processes of the patient. This results with a single, integrated flow as depicted in Figure 2.

## 2.2 Discrete Event Simulator within HIPS

There are several reasons for which a DES is the appropriate tool for analyzing and optimizing processes within a hospital context.

1. A first reason is that the simulator allows the testing of different alternatives next to each other for a broad range of performances based on key performance indicators.

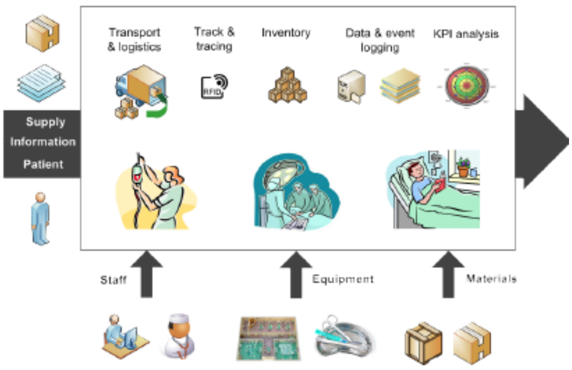


Figure 2: Overview of processes involved (TO BE).

2. Secondly, operational modeling is a trend of the last years and more and more operational processes are decently modeled and documented. Simulating these operational processes is the next step in discovering and visualizing problems such as bottlenecks, deadlocks, inefficient use of material and personal, increasing delays, etc.
3. A third reason we identify is that operational optimization needs to be run while closely monitoring the performance of these operational processes. The performance of an operational process, especially in healthcare, is not simply equal to the cost of executing the process. As such different KPIs of the operational process should be kept in mind while running an optimization, and keeping several such KPIs in mind at the same time is possible by using an operational simulation tool.

For these reasons, a discrete event simulator was developed and applied within the HIPS project. The simulator itself is being explained in the next paragraph.

# 3 DISCRETE EVENT SIMULATOR

## 3.1 Motivation

The key need that the simulator fulfills are summarized below.

1. Finding key performance indicators of the process
2. Finding opportunities for optimization
3. Checking for side effects of an optimization proposal

The identification and monitoring of KPIs over several simulations of an existing process allows us to identify opportunities to optimize this process even further. These opportunities can than also be virtually incorporated in the process and new simulations can provide insight in possible side effects.

Not only the motivation for applying a DES in a healthcare environment is of importance here, but also the architectural choice needs some clarification. There are plenty of DES software tools available, an clear overview was given in (Demyttenaere, 2014). From this list, the decision was made to implement a DES based on the MASON library (Multi-Agent Simulator Of Neighborhoods). There are several reasons for which this approach was chosen:

- A first major requirement was to narrow the list down by removing all commercial software packages. We wanted to have complete control over the code to have the freedom to expand it any way we deem necessary.
- Another requirement that guided our decision process was the preference to make use of the Activiti BPM (Business Process Management) platform (Rademakers, 2012). This requirement implies that the preferred language of the library/framework that will be selected is Java.

Due to these requirements the initial list was heavily reduced. From the remaining possibilities for a DES, the MASON library was selected, which will be further explained in the Simulation paragraph.

## 3.2 Simulator Overview

An overview of a simulated process can be found in Figure 3. Four different stages have been identified in the flow of simulator usage. These are being explained more into detail in the following paragraphs.

1. Input phase
2. Simulation phase
3. Output phase
4. Analysis phase

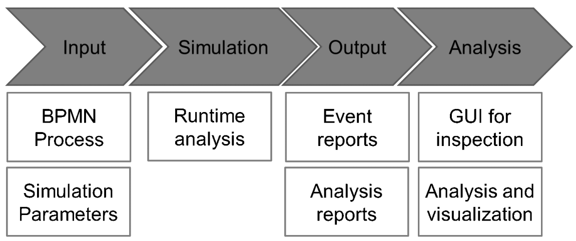


Figure 3: Overview of Simulator Steps.

# 4 INPUT

In a first stage, both the process we want to simulate as well as the parameters that define this process are being delivered as input. A visual representation of possible inputs is given in Figure 4

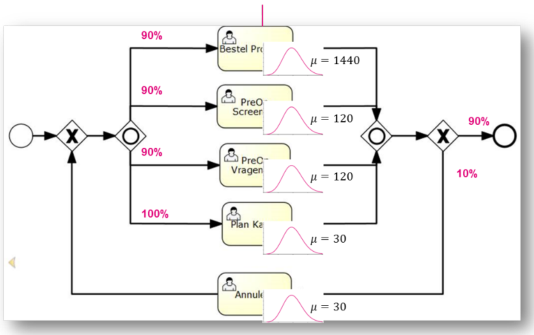


Figure 4: Input Phase.

## 4.1 Process Flow

The process to be simulated has to be provided in the Business Process Model and Notation (BPMN) standard. BMPN is a well-known and widely acknowledged process flow standard with serialization in XML (Extensible Markup Language) format either in a proprietary or XPDL (XML Process Definition Language) format. Our tool works on both XPDL and proprietary Activity serialization format. Drawing the process outline in BPMN, serializing this scheme to xml and loading the xml in the simulator form the first steps in this process.

## 4.2 Process Parameters

Now that we have made the process outline known to the simulator, we also have to provide it with the context in which this process takes place. These context parameters are being provided in an xml file as well. Most of the Simulation Parameters are typically concerning costs and availability of resources and timings and probabilities of the different process steps (Tasks) involved.

Several examples of relevant process parameters in a hospital environmnent are provided below. A first category of parameters are those concerning the resources (employees, rooms, equipment, etc.)

- Concerning **Employees** (Nurses, Doctors, Surgeons, etc.)
  - Availability (expressed in several blocks during a day)
  - Cost (both fixed and variable)
  - Resource Pool (for example, the group nurses can contain doctors, but not vice versa)
- Concerning **Other Resources** (Operating room, Examination room, etc. )
  - Availability (expressed in several blocks during a day)
  - Cost (both fixed and variable)
  - Grouping (for example an Operating room could be used as an Examination room but not vice versa)

A second category of parameters for the process are those related to the execution of tasks in the process.

- Mean Time of task duration
- Distribution of task duration
- Resources required for a task

# 5 SIMULATION

In the next stage in the simulation process, the input from the previous step is being used to run the actual simulation. This is done by means of a Discrete Event Simulator, which models the operation of a system as a discrete sequence of events in time. *"Discrete event simulation, based on a library of event models, is a way of simulating or characterizing cause-effect events that can be described as occurring at one particular moment in time a discrete event. These events are not continuous and have finite result outputs that are selected from a group of available outputs or calculated based on the inputs."* (Hoare et al., 2002) During the simulation, convergence parameters are being monitored to check possible stop or convergence conditions.

The simulator was written entirely in the Java language and was built on top of several libraries, among which MASON. MASON stands for Multi-Agent Simulator Of Neighborhoods and contains a fast discrete-event multi agent simulation library core. (Luke et al., 2004)

Several parameters are being monitored during the simulation to make sure the simulation gets halted when reaching convergence. The predefined criteria that make the simulator to stop running are listed below:

- Convergence of Full Process (Total duration of the process defined)
- Convergence of all Statistics (Every task's duration)

- Maximum amount of Reports in which the data is stored is being reached

## 6 OUTPUT

When the simulation has ended for one of the reasons above, all detailed descriptions of the results are being outputted in xml-files. These include the steps that have been taken, the timings, the amount of resources utilized over time, etc.

All of the raw data is being kept in stand-alone xml files that are used to perform analyses on top of it. This allows us to perform different kind of analyses afterwards, without the necessity to rerun the simulation itself.

## 7 ANALYSIS

To be able to gain insights from these raw data files, there is a final Analysis phase. The custom GUI allows to open and visualize the data graphically. Predefined KPIs are being calculated from the output and these are being plotted in several graphs.

In the hospital context it is very likely that multiple, conflicting KPIs get defined. An overview of several of some of the KPIs we ran into during the HIPS project are the following (De Pourcq et al., 2015):

1. Patient related KPIs
   (a) Number of new patient records, Number of finished patient records, etc.
   (b) Mean lead time, maximum lead time, etc.
2. Process related KPIs
   (a) Execution cost of the process, cost per patient, etc.
   (b) Idle Time
3. Recourse related KPIs
   (a) Usage of each resource (on average, minimal, etc.)
   (b) Idle time of each resource
4. Bottlenecks encountered
   (a) Tasks that cause bottlenecks
   (b) Resources that cause bottlenecks

An optimal level for all of the KPIs is because of the conflicting nature impossible to achieve. Therefore there exist multiple equally rewarding possibilities and the most desirable solution is very much dependent on the preferences of the hospital governance. A multi-KPI overview of each process under consideration can be gained from the simulator and matching these values with the preferences might result in an optimal process design.

Figure 5: Analysis Phase.

## 8 NEXT STEPS AND FUTURE WORK

The current context in which the simulation was developed is the hospital context. Both within and outside of this context can further research possibilities be identified.

Within the hospital environment coexist complex flows of patients, data and supplies. These processes are often susceptible for further optimization. The current simulator allows a lot of this setting to be modeled, but not all of it. Expanding the software to incorporate scheduling algorithms for example might be a valuable next step. Modeling different stock policies might be another possibility. Current research is ongoing concerning the matching of the KPIs with the preferences of hospital governance and visualizing the results. This way, hospital governance can steer the process by adjusting preference parameters and monitor results in a visually attractive way. Another line of work in progress is applying more complex resource selection methods in the simulator. More specifically ontology-based resource allocation in the simulation should more realistic resource selection in future simulations.

Further research possibilities outside of the hospital environment are ubiquitous. For this reason the simulator was built as generically as possible, being able to read in any type of process and resources. This allows completely different processes to be simulated without the need for imminent adjustments.

## 9 CONCLUSION

In this paper we presented the key concepts of a discrete event simulator that can be applied for process simulation within a hospital flow optimization context. An overview of the simulator was being provided and the main steps (Input of process flow and resources, Discrete Event Simulation, Output of raw data and Analysis and visualization) have been explained. Simulating current processes has several advantages. It allows us to monitor key performance indicators of a process, identify opportunities for process improvement and check for possible side effects of process optimization proposals.
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## ACKNOWLEDGEMENTS

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# Towards Lock-Free Distributed Transactions

Rustem Kamun, Askhat Omarov, Timur Umarov
*Department of Information Systems Management, Kazakh-British Technical University, 59, Tole bi str., Almaty, Kazakhstan*
*{r.kamun, askhat.omarov91}@gmail.com, t.umarov@kbtu.kz*

Sanzhar Altayev
*sanzhar@altayev.kz*

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Abstract: For the last 40 years storage systems evolved greatly from traditional relational databases to distributed storage systems. Such dramatic changes are caused by exponential growth of Internet and mostly defined by its users and services (Int, 2014). For the past recent years both industrial and academic projects have recognized the necessity for strong consistency and ACID transactional semantics in large distributed storage systems. The main objective of this paper is to provide such strong consistency in the manner of Googles TrueTime described in (Corbett et al., 2013). We address the limitations of Google Spanner for general-purpose transactions. The result of this paper is a clock synchronization protocol (CSP) for transactions at scale.

## 1 INTRODUCTION

According to the CAP theorem (Gilbert, 2012), presented by professor Eric Brewer any system that relies on persistence layer is characterized by a subset of the following properties: data consistency, system availability and tolerance to network partition. However, distributed systems undergo network partitions which results in impossibility to gain both consistency and availability in distributed storage systems. For the recent years, pressures caused by rapidly growing number of users and data sets have driven system designs away from conventional centralized RDBMs (supporting joins and relational schemes) and toward more scalable distributed solutions, including simple key-value storage systems, as well as more elaborate NewSQL databases that support transactions at scale.

Ideally, a transactional system provides serializability. However, serializability comes with low concurrency and high network overheads. Hence, commercial storage systems use a weaker guarantee, snapshot isolation, since it allows for high concurrency between transactions as well as data replication and partitioning (David Bermbach, 2013).

It is straightforward how to supply data snapshot at some point in time on a single node. One solution is to mark each mutation operation with current wall time on this node. However, choosing a timestamp for transaction executed over multiple nodes is challenge due to clock rate, drift and jitter on each involved node (Mills, 1995; Moon et al., 1999). For this reason there exists clock-based algorithms to order events (ordering transactions, operations and etc.) in distributed services (Marzullo and Owicki, 1983; Lamport, 1978). For example, Amazon Dynamo (Vogels, 2009) uses Vector Clocks (VC) to track causality of mutations to the replicas. Cassandra (Lakshman and Malik, 2010) uses Physical Time and Last-Write-Wins rule on column granularity level to retain consistency during state transition. But both Cassandra and Dynamo sacrifice strong ACID semantics to fault-tolerance and scalability. Google Spanner (Corbett et al., 2013) employs True Time (TT) to provide global ordering between any two non-overlapping transactions. However, TT is built upon special time references (GPS, atomic clocks), wait intervals and high enough bandwidth and speed to guarantee negligible latencies within Google, while we deal with unpredictable network conditions where data transfer rates and physical characteristics of connections vary widely. Using NTP instead of TT with wait intervals in such systems causes several hundred of milliseconds latencies between transactions. In a contended system with long-running transactions (OLTP) and high traffic load, throughput and in turn response rate can decrease significantly. Therefore wait intervals are inappropriate since it may lead to denial of service.

The main result of this paper is a clock synchronization protocol (CSP) for general-purpose transactions at scale. In designing CSP we employed hybrid logical clock (HLC) that leverages the best of logical clocks and physical clocks. HLC is helpful for tracking causality relationship of the overlapping events. CSP is generalized and can meet the needs of any practical system and its efficiency is comparable to NTP and Google TT.

The rest of the paper is organized as follows. In Section 2 we analyze different synchronization methods emerged for the last forty years, provide the basic notations used throughout the paper and analyze the core of clock synchronisation algorithm. In Section 3 we present the core algorithms CSP is based upon. Then, in Section 4 we provide briefly implementation details and show the results of toy example. We conclude the paper in Section 5.

## 2 RELATED WORK

The problem of consistency in distributed systems is tightly related to the synchronization problem. Synchronization of the nodes implies deterministic order of distributed transactions which in turn ensures safety (data consistency and integrity).

In 1978 Lamport proposed a way to order events based on logical clocks (Lamport clocks or LC) (Lamport, 1978). The key property that have to be satisfied by logical clocks is "happened before" condition: for any two events $i$, $j$ in the system, if $i$ "happend before" $j$ then $C(i) < C(j)$. Based on this condition, timestamp assignment described by the two following rules:

- If event $j$ happened locally at some node $P$ after event $i$, then $C(j) = C(i) + 1$;
- If some process $Q$ sends message $m$ to process $P$, then it piggybacks $m$ with a timestamp $T_m$ that equals to $latest\_clock(Q) + 1$. Upon receiving this message (defined as event $j$), process $P$ assigns a timestamp that must be greater or equal to its current value and strictly greater than $Tm$.

However LCs are impractical in distributed storage systems for the following reasons:

- It is not possible to query events with respect to physical time.
- LCs do not consider external events to be a part of their event sets (no back-channels).

Ten years later the vector clock (VC) was proposed by (Fidge, 1988) to extract more knowledge about communication behaviour in the system. Dealing with VC, each node maintains a vector that collects the knowledge this node possesses about the logical clocks of all other nodes. VC finds all possible consistent snapshots, which is useful for debugging applications. However since the number of sites in a popular distributed system can be on the order of thousands, maintenance of the causality information using VC is highly prohibitive because space requirement is in the order of nodes in the system.

Network Time Protocol (NTP) presented by D. Mills at (Mills, 1995) synchronizes computer physical clock with sources known to be synchronized: dedicated time servers, radio and satellite receivers, etc. NTP avoids the disadvantages of LC, however, it provides tens of milliseconds accuracies on WANs which entails an inability of tracking causality of events that has occurred at overlapping uncertainty regions. Moreover, NTP is not accurate due to not stable network conditions (asymmetric routes and congestion) and problems such as leap seconds (Allen, 2015).

TrueTime (TT) was proposed by Google in (Corbett et al., 2013), a multiversion, geographically distributed database. Spanner discards the tracking of causality information completely. Instead, it uses highly-precise external clock sources to reduce the size of the uncertainty intervals to be negligible and order events using wall-clock time. Such ordering in TT is stronger than the causal happened-before relation in traditional distributed system since it does not require any communication to take place between the two events to be ordered; sufficient progression of the wallclock between the two events is enough for ordering them. TT enables lock-free reads in Spanner; it provides simple snapshot reads by just giving a time in the past. Snapshot reads is not an easy task to accomplish in a distributed system without using TT. This would require capturing and recording causality between different versions of variables using VC, so that a consistent cut can be identified for all the variables requested in the snapshot read. However using VC is infeasible as we discussed previously.

When the uncertainty intervals are overlapping, TT cannot order events and that is why in order to ensure sufficient progression of the wallclock between these events it has to explicitly wait advertised uncertainty interval. Moreover this approach requires access to specialized hardware (GPS and atomic clocks) to maintain tightly synchronized time at each node. These limitations causes Google approach to be inappropriate for general-purpose transactions where the waits on uncertainty bounds can significantly decrease the concurrency and in turn system availability. Given the importance of transactions in large-scale software systems, we decided to design an alternative clock synchronization protocol with more viable properties for general-purpose than Google Spanner.

Kulkarni et al. (Kulkarni et al., 2014) introduced a Hybrid Logical Clock (HLC) algorithm that avoids all disadvantages mentioned in TT, LC and NTP. HLC leverages both LC and PT. The HLC timestamp is within 64-bit of NTP timestamp. When the uncertainty intervals of two events are overlapping, the LC part of HLC tracks the causality between these events.

# 3 DESIGN OF CSP

Before we dive into algorithm details CSP is based upon, it is important to understand terminology and notations used throughout the paper. $pt(n)$ is a current wall time at node $n$. $l(n)$ is a largest wall clock time among all events occurred so far at node $n$. $c(n)$ is logical part of HLC that tracks causality between two events when their $l$ parts are equal at node $n$. When message $m$ is sent to node $n$, it piggybacks with $< l(m), c(m) >$ by some server $i$. $\varepsilon$ is a heuristic parameter that defines how far ahead of physical clock the wall time can be or simpler, it defines an upper/lower bound for offset on a single node. $hlc(n)$ is a hybrid logical clock or a more verbose version is represented by a pair $(l(n), c(n))$.

## 3.1 HLC Timestamping

There are two types of event handled by HLC algorithm: send(local), receive. Figure 2 outlines an HLC algorithm. Initially, l and c parts are set to 0. When a new send event $f$ is created at node $n$, $l(n)$ is set to $max(l'(n), pt(n))$, where $l'(n)$ is a previous assigned value or 0. However, it is still possible that $l(n)$ is equal to $l'(n)$ and if that is the case then we increment its logical part, $c(n)$, by 1. Otherwise, set $c(n)$ part to 0. If at any point in time, receive event $f$ is occurred at node $n$, $l(n)$ is equal to $max(l(n), l(m), pt(n))$. If $pt(n)$ is greater than both, $l(n)$ and $l(m)$, then set $(n)$ to 0 and return a pair $< l(n), c(n) >$. Otherwise, $c(n)$ is set depending on whether $l(n)$ equals to $l(e)$, $l(m)$, or both. By incrementing $c$ parts in the just mentioned cases, HLC provides important invariant: for any two subsequent events, $e$ and $f$, occurred at some node $n$ if $e$ occurred before $f$, then $hlc_e(n) < hlc_f(n)$ (Kulkarni et al., 2014). Figure 1 depicts how algorithm works on a "space-time" diagram. The horizontal direction represents space. The vertical direction is time with earlier times being higher than later times. Each box represents an event marked by hlc timestamp. The vertical lines denote nodes, and the arrows denote messages between them.

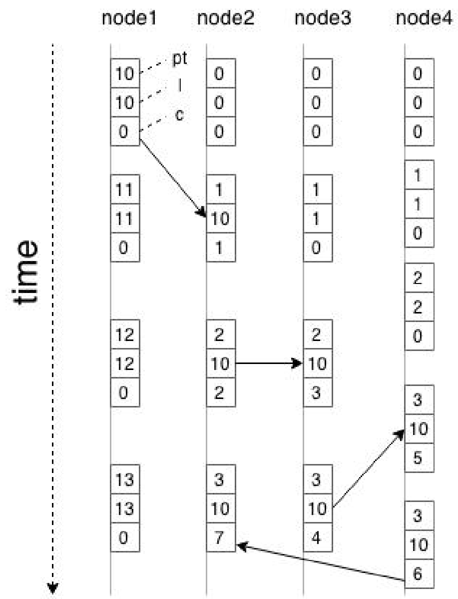


Figure 1: Space-Time diagram of HLC algorithm.

The major benefit of HLC is its agnosticism to network conditions and to architecture of distributed system. Instead of tweaking the node's local clock, HLC only reads it and updates $l$ and $c$ parts accordingly. Although HLC leverages NTP for synchronization, it can use any other clock synchronization algorithm/protocol.

Kulkarni et al. (Kulkarni et al., 2014) advice to set $\varepsilon$ to sufficiently large value depending on application constraints in order to be resilient to clock synchronization errors. But it would be abnormally large space for $(l - pt)$ offset in case of distributed transactional storage system. It can significantly increase the number of aborted/restarted transactions in the system and decrease the concurrency level proportionally. Hence, we decided to maintain maximum offset, $\varepsilon$, at each involved node within several hundred of milliseconds for NTP in the manner of Google Spanner (Corbett et al., 2013) (the $\varepsilon$ can be improved further, if the network conditions are more optimistic (e.g. geographically-proximate clusters)).

## 3.2 Offset Maintenance

Offset maintenance is implemented at each involved node in the cluster. Each node in the cluster maintains the list of remote clocks. Remote clock is a local clock of any node in the cluster (wallclock) except

```
function SENDTS
    if l(n) ≥ pt(n) then
        c(n) ← c(n) + 1
    else
        l(n) ← pt(n)
        c(n) ← 0
    end if
    return < l(n), c(n) >
end function
```

Send or local event

```
function RECEIVETS
    if pt(n) > l(n) & pt(n) > l(m) then
        l(n) ← pt(n)
        c(n) ← 0
        return < l(n), c(n) >
    end if
    if l(m) > l(n) then
        l(n) ← l(m)
        c(n) ← c(n) + 1
    else if l(n) > l(m) then
        c(n) ← c(n) + 1
    else
        if c(m) > c(n) then
            c(n) ← c(m)
        end if
        c(n) ← c(n) + 1
    end if
    return < l(n), c(n) >
end function
```

Receive event of message *m*

Figure 2: HLC algorithm

for the maintainer node. It is easy to understand the key parts of the algorithm by an example. Assume a cluster with three nodes: 1, 2 and 3. Then node 1 will maintain a list of remote clocks $[HLC(2), HLC(3)]$. To maintain a single remote clock of node $i$, node $j$ periodically polls it. During each such round-trip, node $j$ applies a version of Cristian's algorithm (Iwanicki et al., 2006; Cristian and Fetzer, 1994) to estimate node's $i$ clock as depicted at Figure 3.

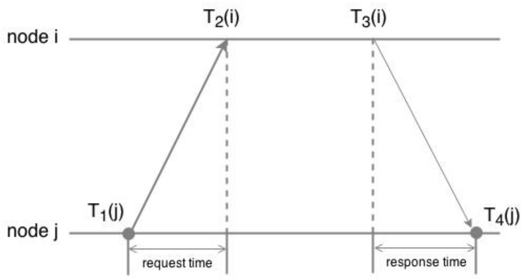


Figure 3: Christian algorithm.

Later, the node $j$ records an HLC timestamp $T_1(j)$ and sends a heartbeat message to node $i$. After reception of this message, $i$ records timestamp $T_2(i)$ according to its local clock and starts to prepare a response message containing the recorded timestamp. When the message is ready, $i$ records timestamp $T_3(i)$, piggybacks a pair $< T_2(i), T_3(i) >$ within a response message and sends it back to $j$. As soon as the message is delivered, $j$ records timestamp $T_4(j)$ according to its local clock. At this point, node $j$ has the following set of timestamps: $T_1(j)$, $T_2(i)$, $T_3(i)$, $T_4(j)$ (called a synchronization sample). Since the propagation delays from $i$ to $j$ and from $j$ to $i$ are comparable, the sample allows $j$ to estimate the round-trip delay (eq.(1)), the offset of $i$. (eq.(2)) and clock reading error (eq.(3)):

$$\sigma = T_4(j) - T_1(j) - (T_3(i) - T_2(i)) \quad (1)$$

$$\theta = T_3(i) + \frac{\sigma}{2} - T_4(j) \quad (2)$$

$$\xi = \frac{\sigma}{2} \quad (3)$$

Finally, node $j$ updates information about node $i$'s offset, error and the time of measurement.

Periodically (multiple of heartbeat interval) node $j$ uses the list of remote clocks $C(i)$ (where $i \in [1,N] \wedge i \neq j$) and applies Marzullo's intersection algorithm (Marzullo and Owicki, 1983) to estimate a "true" offset using $N-1$ sources. The outcome of algorithm depends on an important property – *majority of sources*. So, for $N-1$ sources, the offset is considered "true" if and only if $\frac{N-1}{2}+1$ sources are intersected at it. If the estimated offset is greater than allowed $\varepsilon$ then node $j$ is evicted. Thereby the system is protected against nodes with broken clocks. It implies that at any node in the system clock uncertainty is maintained within $[-\varepsilon, +\varepsilon]$ bounds.

# 4 IMPLEMENTATION OF CSP

Current implementation of CSP is built on the following technology stack[1]:

- Application layer is built using python gevent[2].
- Lightweight persistence layer is based on etcd[3].

The algorithms and methods mentioned in Section 2 involve tight interaction between nodes in the cluster. To facilitate a proper interaction of nodes and execution of CSP in overall, we implemented/used the following protocol stack: 1) "All-to-all" heartbeating 2) "Liar's suicide" protocol 3) HLC 4) NTP. Further we discuss the key role of yet to be mentioned protocols. At the end of this section we describe the toy example that exemplifies implemented CSP.

## 4.1 "All-To-All" Heartbeating

As soon as node joins the cluster it starts maintaining membership changes (joins, drop-outs and failures) and clock of every other node in the cluster by exchanging RPC messages. The general workflow looks as follows:

1. Every cluster member periodically transmits a "heartbeat" message to all other group members.

[1]source code could be obtained at github repository available by https://github.com/Rustem/tt.

[2]A coroutine-based Python networking library that uses lightweight pseudo threads to provide a high-level synchronous API on top of the event loop.

[3]A distributed consistent key value store

2. Every node $i$ is considered failed by a non-faulty member $j$ when node $j$ does not receive heartbeats from $i$ for certain time period $T_{heartbeat}$.
3. Every node, received a "heartbeat" request, responses with a message piggybacked with $T_2(i)$ and $T_3(i)$ (receive and send timestamps) that are further used to estimate clock offset.

The heartbeat request and response message structure is depicted in Figure 4.

```
message HeartbeatRequest {
    optional string ping = 1;
    optional int64 counter = 2;
}

message HeartbeatResponse {
    optional string pong = 1;
    optional int64 counter = 2;
    optional int64 recv_time = 3;
    optional int64 send_time = 4;
}
```

Figure 4: Heartbeat protocol

## 4.2 "Liar's Suicide" Protocol

A liar is the node that has a broken local clock. Clock is considered broken if it exhibits frequency excursions larger than the worst-case bound. Such nodes must be evicted from the system to maintain an advertised $\varepsilon$. To distinguish such nodes, we propose an algorithm (similar to Spanner) that is based on clock offset maintenance. Clock offset denotes how far one clock ahead of other clock. Single offset message about some node has structure as depicted at Figure 5.

```
message RemoteOffset {
    optional int64 offset = 1;
    optional int64 error = 2;
    optional int64 measured_at = 3;
}
```

Figure 5: Offset protocol

Each node maintains a list of remote clock offsets. Every $T_{monitor}$ interval (equal to $c * T_{heartbeat}$, where $c$ is a positive constant) is an each member of a cluster applies Marzullo's algorithm on that list to estimate its current "true" offset interval. If the interval is either not shared by the majority of the references or out of uncertainty bounds, then the node is considered as a liar, which in turn causes it to suicide.

## 4.3 Toy Example

The main goal of an example application is to demonstrate the distribution of logical clock value under massive loads. The example application could be summarized as follows: each node generates local events as well as sends messages to other nodes with the same predefined rate. Each received event (message) is assigned with HLC timestamp and stored in the database. Example application has the following environment: there are three nodes in the system hosted at different racks in Amsterdam. As hosting provider we have chosen Digital Ocean [4]. One of the nodes is master node. Each node has the following characteristics:

- Hardware: 4GB of RAM, 60GB SSD Disk, 2xIntel Hex-Core CPUs
- Software: Ubuntu 14.04 OS, Python 2.7.6. Each node is configured with NTP stratum 2. Master node is equipped with database PostgreSQL and configuration in-memory storage, etcd.

This example has tested under different event rates: *a*) 100 messages per second as shown at figure 6 *b*) 1000 messages per second as shown at figure 7. For the first case, the maximum logical value is 3. 98% comprised logical value of 0 and 1. The overall offset was between 5-10 ms. For the second case, the maximum logical value is 23. 60% of the total comprised logical value range 0-7. The overall offset was between 16-20 ms [5].

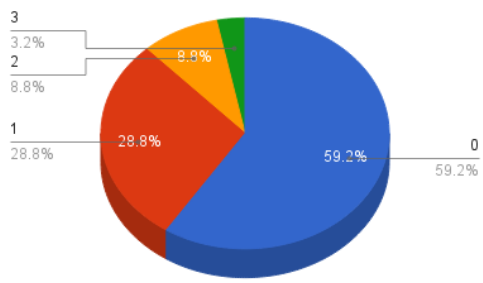


Figure 6: Distribution of logical value (100 msgs/sec).

# 5 CONCLUSION

In this paper, we introduced the clock synchronization algorithm (CSP) that combines the benefits of both physical and logical clocks. CSP uses HLC

[4]https://www.digitalocean.com/

[5]Statistics has built on a dataset with more than 50 000 messages

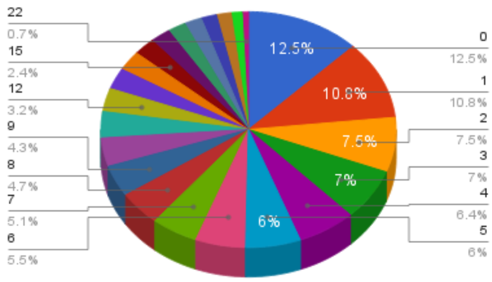


Figure 7: Distribution of logical value (1000 msgs/sec).

for timestamping and therefore it is viable for arbitrary distributed architecture. According to the benchmarks presented in (Kulkarni et al., 2014), deployed in WAN, even in the presence of straggler nodes and high event rate, the logical part, $c$, of HLC was no higher than 1000 (though only at the struggle node). In addition, HLC is backward compatible with TT and LC. When $\varepsilon$ is infinity, CSP behaves more like an LC used for causality tracking in asynchronous distributed systems. When $\varepsilon$ is small, CSP behaves more similar to Google TT. In the manner of Google Spanner, we have leveraged the stack of distributed protocols/algorithms to keep clock offset at any node within advertised bounds. In turn it ensures another level of CSP resiliency to different types of errors.

A snapshot read with our implementation is similar to TT-based Spanner. For a snapshot read of data items $x$ and $y$ at absolute time $t$, the client executes the reads at nodes $i$, $j$ that are hosting $x$ and $y$ and that are sufficiently up to date (updated to at least $t-\varepsilon$). Let $t_x$ (respectively $t_y$) denote the timestamp of the latest update to $x$ (resp. $y$) before $t-\varepsilon$ at $i$ (resp. $j$). Reading the values of $x$ at $t_x$ and $y$ at $t_y$ gives a consistent snapshot because at time $t$ the values of $x$ and $y$ are still the same as those at $t_x$ and $t_y$ by definition of $t_x$ and $t_y$. However, if say $x$ has another update with timestamp $t'_x$ within the uncertainty interval of $t_x$ then we use HLC comparison to order those two to identify the latest version to return from $i$.

CSP can provide a slightly relaxed version of the external-consistency guarantee in TT-based implementation of Spanner. In case, when a transaction $T1$ commits (in absolute time) before another transaction $T2$ starts, it is still possible to have an overlap between the uncertainty intervals of $T1$ and $T2$. In case $T1$ and $T2$ are causally-related then CSP will still give the same guarantee as TT because $T2$'s assigned HLC timestamp will be bigger than $T1$'s. Otherwise, CSP will give a slightly relaxed guarantee and will only ensure that $T2$'s assigned HLC commit timestamp will not be smaller than $T1$'s.

In nearby future, our main objective is to bring general-purpose transactional protocol with CSP at its core to Open-Source.

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# POSTERS

# Experiences of Tool-Based Enterprise Modelling as Part of Architectural Change Management

Cameron Spence
Capgemini, Woking, United Kingdom
*cameron.spence@capgemini.com*
*c.d.spence@pgr.reading.ac.uk*

Vaughan Michell
University of Reading, Whiteknights, Reading, United Kingdom
*vaughan.michell@reading.ac.uk*

Keywords: Enterprise modelling, business modelling, enterprise architecture.

Abstract: Enterprise Architecture is widely practised as a part of a strategic business change methodology and is often vital to successful business change. This paper examines the pragmatic use of enterprise architecture modelling (EAM) tools. A pilot survey of EAM practitioners identified that many companies abandon the use of EAM tools despite the benefits that should result from their use. Some of the reasons for lack of sustainability include (a) failures in modelling governance, (b) lack of alignment with the change method, (c) users withholding information and (d) poor perception of EA itself.

## 1 INTRODUCTION

Enterprise architecture is a growing field that enables the major aspects of business and IT activity to be modelled and plans made for their change (Hoogervorst, 2004). The use and application of an integrated model of the business is key to supporting change decision-making. However, a survey of the current literature identified firstly that EA modelling is often abandoned (e.g. (Meertens et al., 2011b)); secondly that business models vary greatly and do not have a clearly agreed definition (Vermolen, 2010)); and thirdly there is a gap in the existing literature regarding how enterprise architecture modelling (EAM) can be made sustainable and effective in its use as part of a principle change methodology.

This paper first summarises some relevant terminology related to the modelling of Enterprise Architecture. We then present results from a pilot survey of practitioners of enterprise architecture modelling (EAM) based around the issues identified from the literature. We then consider a number of issues identified by the respondents in the execution of tool-based EAM as motivation for further study.

## 2 THE PRACTICE OF TOOL-BASED ENTERPRISE MODELLING AS PART OF CHANGE MANAGEMENT

Enterprise Architecture Modelling (EAM) is carried out in both end-user and consulting organisations (Hall and Harmon, 2005, Ganesan, 2008). This section briefly explains and grounds some terms related to tool-based EAM.

### 2.1 Enterprise Architecture

Rood (Rood, 1994) suggests an Enterprise Architecture comprises: people, information and technology. TOGAF (The Open Group, 2011) divides the Enterprise into four domains: Business, Data, Applications and Technology. Capgemini's IAF (Wout et al., 2010) uses four similar domains to

TOGAF, but worded slightly differently. All broadly recognise the need to cover business, information and technology.

## 2.2 EA Frameworks

These provide a standard structure, vocabulary and (sometimes) a process for carrying out EA work. Examples of EA frameworks include TOGAF (The Open Group, 2011)), DODAF (DoD, 2010)) and Zachman's Enterprise Architecture Framework (ZEAF) (Zachman, 1987)). There are also reference frameworks that help position and compare the EA frameworks: the Generic Enterprise Reference Architecture and Method (GERAM) (Bernus and Nemes, 1996) which packages these within Ontological Theories; and the newer EAF2 (Franke et al., 2009).

## 2.3 Enterprise Architecture Model

An Enterprise Architecture Model is a miniaturisation or representation of the components making up an enterprise. These models might take a number of forms, but are likely to consist (in terms of content) mainly of representations of the entities, attributes and relationships relevant to a particular viewpoint or perspective. These may for example support decision making (e.g. "show me a view of all business services that are reliant upon obsolete infrastructure", as described in (Spence and Michell, 2011). This is helpful in governing the evolution of the enterprise IT portfolio, as discussed later.

## 2.4 Enterprise Architecture Modelling

EAM is the activity of producing and maintaining EA Models. The content of the models may well be created by multiple agents, and also viewed by multiple agents for a variety of reasons. These agents will need views tailored to meet their specific needs, showing different entity subsets, attributes and relationships. The selection and creation of these views and the entities and attributes in them, may or may not be specified by a particular architecture framework in use, but will typically need adapting to the specific context needed for modelling. This drives the need for EAM tool to be customisable.

## 2.5 Enterprise Architecture Tools

An EA Tool is an instrument used for EA Modelling. Whilst EA Models can use pen and paper, or simple drawing tools (e.g. Microsoft Visio®), it is much more efficient using a software tool designed specifically to do the job (Hall and Harmon, 2005).

TOGAF 9.1 (The Open Group, 2011) refers to EA tools, (in chapter 42) as "automated tools". This paper focuses on tool-based EAM, as distinct from non-tool-based EAM.

Commercial research organisations (Brand, 2014, Peyret et al., 2011, Hilwa and Hendrick, 2012) divide "modelling and architecture tools" into the following categories:

- Object Modelling tools
- Business Process Modelling Tools
- Enterprise Architecture Tools
- Data Modelling Tools

EA Tools are, in terms of revenue, the fastest growing in this particular market segment [21]. When combined with a large failure rate (our survey indicated perhaps an 85% failure rate, if failure is defined as the modelling having ceased) from modelling efforts, we can see that aside from failure to gain the required benefits, the amount of spend on EAM tools that ends up being wasted might be in the region of $230M in 2016 (if the percentage failure rate in our qualitative survey were to be representative of general EAM activities).

# 3 TOOL-BASED ENTERPRISE ARCHITECTURE MODELLING EXPERIENCES

To explore whether the EAM issues identified earlier in the literature (such as (Meertens et al., 2011b), discussed later) occur in practice, we carried out qualitative research. We interviewed seven consulting Enterprise Architects who responded to an email invitation sent to approximately 400 staff within an IT services company, seeking volunteers to be interviewed that had prior experience with tool-based EAM. This is not as small as percentage as it may appear, given that the majority of the staff will have had no experience with EA modelling tools, which are not used as standard within this company; and so the pool of qualified subjects available at this stage was relatively small.

A set of structured/ telephone interviews was carried out on the respondents. As our future research direction is focused on the value of the tool-based EAM, and the factors affecting its sustainability, we gathered information about the value (expected and perceived) of the EAM effort and what lessons were learned. Some questions also related to possible activities that might lead to it being more sustainable. The key questions were:

- Who was the client, in what industry sector?
- What EA tool was used?
- How was the tool used (e.g. single/multiple users, one-off or part of lifecycle process, were multiple users able to do updates in parallel)?
- What support was given (training, coaching, documentation)?
- What was the scope of the modelling (business, information, technology)?
- Who was responsible for introducing the tool (client or supplier)?
- Who paid for the tool?
- What value did the client, and the supplier, expect to get from it?
- How was that, or how could that been, measured?
- What value did the client, and the supplier, actually get from the tool?
- What processes were in place to support and govern the use of the tool?
- What were the factors in the modelling environment (people, process or technology) that helped the EAM activity? What factors hindered it?
- Are there any features of the tool that would help, or hinder, its sustained use over the longer term?
- Is the client still using the EA tool? If not, why not?
- In hindsight, what do you wish you had known before you started using the tool, and what would you change if you did it again?

A summary of the key results is offered below. These reflect a subset of the answers to the questions posed:

Table 1: Summary of Some EA Modelling Experiences.

| Expected value | Actual value | What helped | What hindered | Still in use? | Abandoned because |
|---|---|---|---|---|---|
| Quicker project lifecycle reducing costs and risks due to less ambiguity | Projects were no faster as decisions delayed anyway | Training; top-down initiative | Cultural and political issues; the need to win people over | ? | |
| No specific expectations | Single version of truth; enabled persuasion and challenge; detect errors, saved wasted effort and time | Many ways of creating a model; not one fixed standard | Not enough people had access to tool; cultural resistance | Barely | Seen as opposed to Agile ("high ceremony") |
| Supplier made it prerequisite for replatforming IT estate | Saved a month by skipping due diligence as information was already captured | Librarian role; buy-in from business; publishing results; lessons learnt; people signing off on content | Tool struggling to produce suitable diagrams; scope unclear at start; people holding onto 'their' information | No | Replatforming finished; client believed they no longer needed the information |
| Looking to save money, so required to understand the IT estate and therefore support rationalisation | Unsure but client architects seemed pleased | Having a librarian for the tool; having clear scope for modelling | Tool not easy to use; lack of training | Yes | |
| Traceability – impact of change – how strategy is | Understood impact of change | Tool supplier staff very helpful; easy to use; | Tool reports sometimes hard to read; some tool | No | Unknown |

| | | | | | |
|---|---|---|---|---|---|
| worked out in IT projects | | | features non-intuitive | | |
| Understand IT estate as prerequisite for application rationalisation and modernisation | Complete picture of their estate to enable application rationalisation | Having core modelling team to help others; quality control | Lack of governance; reporting hard to configure | No | Tool issue (reporting) and process issue (not following proper processes) |
| Understand IT estate as prerequisite for application rationalisation | Ability to perform complex analysis, communicate business value | Repository management features, ease of customisation | Tool quirks; high cost of tool | No | Client felt tool was too expensive |

This pilot survey clearly suggests there is an issue sustaining the use of EA tools; it confirms that the majority abandoned the use of EAM (see "Still in use" column in table). This prompts the research question: why? - In only one of the 7 case studies has the end-user organisation continued to carry out the modelling activity, in some cases despite the benefits that were being obtained.

The failure to produce benefits has been traced in some cases to issues with the way it was being used (e.g. "our *main issue was caused by people not following process / guidelines, and not updating repository as designs were changed*").

In some cases the issue was with the tool itself (e.g. "*the client realised that the repository couldn't actually be generated from the tool, they believed it couldn't deliver the expected value: format wasn't good*").

# 4 DISCUSSION OF SURVEY RESULTS VS RELEVANT LITERATURE

This section sets the results in the context of the current literature.

A systematic review of business modelling carried out in 2010 (Vermolen, 2010), relating to the Business layer of Enterprise Architecture concluded that literature related to business modelling had a gap in terms of the use of theory; and that there appears to be a lack of papers in the leading IS journals on the topic of business models.

Meertens et al. (Meertens et al., 2011a) recognises that many projects involving business modelling (a subset of EA modelling) end after an initial phase and do not deliver the expected benefits; this mirrors our experience from the limited case studies above.

The topic of business modelling is the subject of much existing research, including a proposed research framework published in 2004 (Pateli and Giaglis, 2004), which organises business model research into a number of categories including "Design Methods and Tools" and "Adoption factors", both of which seem initially to be relevant to the topic at hand (sustainability of EA modelling). Some primary and secondary sources are organised according to these categories. In the Design Methods and Tools category, papers describing two specific modelling languages (UML (Eriksson and Penker, 2000) and eBML (Lagha et al., 2001)) are listed, but nothing that addresses the specific question of the value of Enterprise Architecture modelling using tools such as discussed above.

The motivations for EAM are to allow the visualisation and reporting on aspects of the Enterprise Architecture (part of the governance referred to below), and to provide an environment where the structure of the Enterprise can, in a simulated fashion, be altered in some way to examine the consequences of the alternation. There may be specific business scenarios that lend themselves to this kind of activity, for application rationalisation (one of the scenarios encountered in the survey), or mergers and acquisitions (Freitag and Schulz, 2012). Some of the tasks mentioned in this paper are related to expected business benefits, for example carrying out due diligence (to reduce risk and cost through better knowledge). However, the study does recognise that the literature does not confirm (or disconfirm) that using this kind of EA management technique (including modelling) improves the success rate of mergers and acquisitions.

The literature surveyed so far focuses mainly on discrete elements (for example, specific methods or languages), rather than the activity of EAM that draws them together for a particular benefit. The value of business process modelling in particular is discussed by Indulska (Indulska et al., 2009) where three particular areas of concern are raised; two of these have potential relevance in areas wider than just business processes (standardisation of modelling approaches and the identification of the value proposition of the modelling). Standardisation of the modelling language is covered by Lankhorst (Lankhorst, 2013), as is the use of a particular modelling tool.

The value of the modelling seems to be assumed by Jonkers (Jonkers et al., 2004) to relate to "informed governance" and references (Op't Land et al., 2008) that discusses the value of EA in terms of the governance of an enterprise and its transformation. The relationship between the acquisition and use of a tool and a major transformation initiative is illustrated in one of the cases surveyed, where a supplier insisted that the modelling had to be done as a prerequisite for a replatforming effort. The survey suggested that some, but not all, modelling was done explicitly in order to help a particular transformation exercise; and that having a clear reason for the tool is no guarantee that its use will be sustained over time.

Given the link between EA and IT governance, this suggests that one line of reasoning that may bear further research, related to IT governance and tool-based EAM, might be:

(1) Effective IT governance requires EA
(2) Effective (accurate and comprehensive) management of EA information requires an EA tool
(3) Effective IT governance requires an EA tool (from (1) and (2))

Echoing a comment from one of the pieces surveyed, there is a need to do further research in a number of related areas:

- What is the value that we can actually expect to get from this activity (tool-based EAM), and in particular can the argument related to IT governance be more clearly clarified and investigated?
- What needs to be done in order to make this sustainable rather than a short-term activity?

# 5 CONCLUSIONS

We have identified that although widely used as a part of change management, EAM is often abandoned and that there is a lack of formal definition and understanding of the benefits of these models. We have shown in a pilot survey in section 3 that there may be an issue in practice with the sustainability of attempts to execute EAM; these include:

- Issues with the tool itself
- Poor governance of the modelling
- Perception of EAM and EA being unnecessary
- Lack of ability to tailor the tool
- Need for cultural change
- People not wanting to share their information
- Modelling scope is not always clear
- Need to maintain quality in modelling

We have also identified in section 4 a gap in the literature related to tool-base EA modelling as a discipline. There is little work done on tool-based EAM, and in particular in the business domain, a lack of common understanding about what business models should comprise. There is a recognition that business modelling efforts often fail, with little analysis of why this is so, and what should be done to improve the situation. We have also identified a possible direction for future research, related to the value that tool-based EAM adds to Enterprise Architecture and hence to IT governance.

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# MagLab – An Intelligent Management Learning Environment

Rallis C. Papademetriou
*School of Engineering, University of Portsmouth, Portsmouth, United Kingdom*
*Rallis.Papademetriou@port.ac.uk*

Keywords: Management Analytics, Education, Intelligent Learning Environment, Tcl/Tk, GUI

Abstract: In this paper, the perceived difficulty for students learning purely through auditory and visual means, such as via the standard lecture format, is highlighted through a literature review of learning styles and methods, and a solution based upon interactive computer case-based learning is proposed through a new and continuously evolving simulation environment called *Management Laboratory*, or simply *MagLab*. The software was developed using the open-source, high-level scripting language Tcl/Tk and it was designed to run under both Unix/Linux and Windows. An insight into the characteristics of MagLab brings out its many capabilities and strong points of simplicity, user friendliness, intelligence and extensibility.

## 1 INTRODUCTION

This paper describes the development of a student-centred teaching and learning methodology within the field of Management Science. It is important that learners acquire knowledge and experience in the contextualized use of analytical management techniques since these have a broad specification. Furthermore, theories to do with different styles of learning are very well rehearsed in this day and age and the development of interactive packages to assist students with their learning is highly relevant when these are considered. As described by Lepi (2012), it is important to keep in mind that learners broadly learn via an auditory, visual or kinaesthetic style of learning. Whilst it is the case that most learners may use an amalgamation of all three styles, there is nevertheless much evidence to suggest that learners do tend to have a preferred style of learning. Traditional lectures may capture the interest of an auditory-based learner, albeit with some limitations based upon the length of time an individual can concentrate. The addition of graphics and visual aids such as 'Power-point' can be used to help assist the visually stimulated learner. However, it is generally the case that unless an activity is very practical and/or laboratory based, many learning sessions do not provide the kinaesthetic learner with many opportunities. This paper seeks to address the problem learners have in accessing, understanding and using material in the field of Management Science by developing a learner-centred, interactive, computer-based package. The interactive package described here integrates different styles of learning and gives the student every opportunity to progress at his or her own rate. Allowing students to proceed at their own rate is highly important (West, 2013). Learners tend to acquire knowledge and confidence in material at different rates and the interactive package described in this paper fully recognizes this important fact.

## 2 RELATED WORK

The plethora of management tools currently available presents an overwhelming choice to users of various needs. Commonplace is tools developed for specific markets, like OR/MS (Hillier, 2014) used in academia and MPSIII (Ketron, 2011) used in the commercial market.

Both markets present packages that support a specific group of techniques, for example a package offering support for Linear Programming (e.g., MPSIII) typically will not support Game Theory. This forces users, who wish to explore a range or combination of techniques for solving a problem, to require access to a number of different software packages and acquire the ability to operate them.

Predominantly, packages are provided by different vendors and operation is targeted to audiences with specific needs. This has led to reduced *conformity of operation* among packages due to the varying design criteria used by each vendor. These criteria could affect elements as the GUI (graphical user interface), input and control method (files, mouse and keyboard), operating platform (UNIX, Windows, MacOS) and the balance of theoretical and practical focus.

In the area of *learning environments,* for academic purposes, the available packages are commonly linked to specific platforms and support an accompanying course or book, resulting in limited tools heavily related to the material covered therein. Conversely, packages aimed at the commercial market tend to offer *solution tools*, neglecting the provision of theoretical revision or offer exploration of new techniques through education, preventing the development of additional skills by the employee.

## 3 MAGLAB - INNOVATIVE FEATURES

A contemporary discussion of interactive learning systems with respect to modern theories of education (Schank, 2010) lists the following five different teaching architectures: (i) **simulation-based learning by doing**, (ii) incidental learning, (iii) learning by reflection, (iv) **case-based teaching**, and (v) learning by exploring.

In this work, the focus is on the first and fourth of these teaching architectures. Simulation-based learning by doing is critical when the subject matter is experiential at heart. Emphasis is made on learning by doing and preparing the student for the challenges that might be faced with real world problems. Case-based teaching is described as being a useful addition to that of learning by doing – sometimes students will realize that in order to progress in their 'doing', they need further knowledge. This can be achieved through the use of case studies. While isolated facts may be difficult to remember, if knowledge is presented in the form of a story or particular case, it is generally integrated better into memory.

MagLab is an intelligent *interactive learning environment,* that provides a wide ranging theoretical content, backed with calculation tools that can be used as problem solvers, implemented in an expandable and integrate-able fashion. The integration framework allows for the masking of the underlying application and applied theory by a highly intuitive and usable interface. An example of the MagLab interface can be seen in figure 1.0, which demonstrates the use of MagLab as a *learning* or *reference tool.*

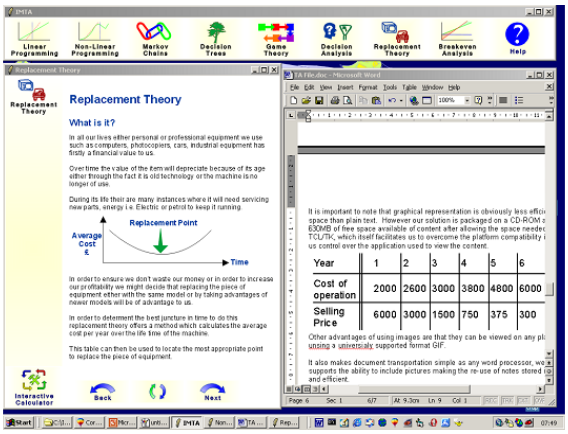


Figure 1: MagLab environment providing theoretical assistance to a user while they are developing a document in a word processor – in this example relating to a Replacement decision.

The environment uses common MOTIF interface components such as *navigational anchor bars* (top of the screen) and *icons*, which remove language barriers and facilitate navigation between sections. Theory content and calculator tools as well as interactive exercises are provided in independent *windows* ("*Theory window", on the left in figure 1*) assembling an interactive learning environment, where users can study theory, step through methods, review examples and answer questions through independent high level scripts. The *independent window* environment facilitates the use of other applications such as word processors or spread-sheets in conjunction with MagLab, assisting users through their learning or decision making process; an innovative convenience against other packages. MagLab uses the high level scripting language Tcl/Tk (standing for **T**ool **C**ommand **L**anguage/**T**ool **K**it) (www.tcl.tk/software/tcltk), which provides support for powerful GUIs (graphical user interfaces). Tcl is a very simple but powerful and dynamic language that allows implementation of complex programs and functions with very few lines of code (Flynt, 2012). The Tcl scripts call on the Tcl core to provide their functionality.

The use of Tcl/Tk gives MagLab an advantage over existing packages by providing true cross platform compatibility, requiring only a Tcl/Tk interpreter per platform and removing the need for code recompilation. The interpreter is *royalty free*, which removes licensing issues (traditionally found with cross-platform applications) and allows MagLab to be provided in a run-from-disk format with no installation required. So, a student, for example, could use the Unix/Linux version of MagLab for work in the university laboratory and the Windows version for work at home. Also, desktop Tcl/Tk programs may run almost unaltered on the Android Platform (AndroWish, 2014).

Tcl provides network and internet access through TCP/IP, allowing provision for online content and updates for collaborative or distance learning, as figure 2 illustrates.

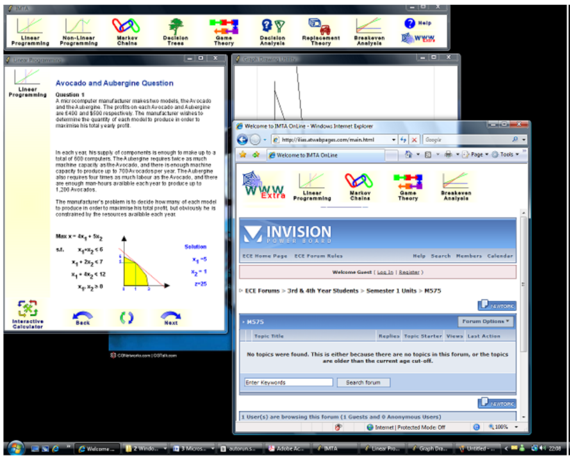

Figure 2: Software running along with IE in windows.

Online forums and online chat are easily implemented on a web site and no alterations need to be made on the software since it already provides a link to the web. Also perception tests can be developed on the server's side for accessing purposes. Web features can be additionally used for the support of the software with updates and technical support as well as providing extra online content.

Other features of Tcl allow third party applications to be 'glued' on to MagLab allowing integration of powerful third party routines in *Interactive Calculators*. These calculators provide users with real tools to be used in problem solving at the workplace or experimentation to support learning.

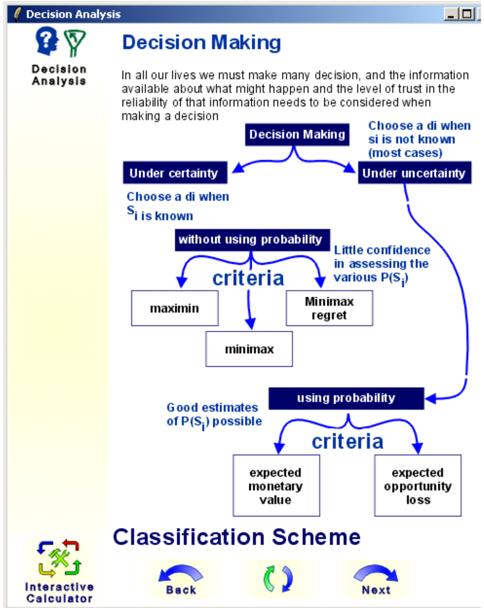


Figure 3: Interactive decision making environment provides assistance on the selection of theoretical techniques without the need for prior knowledge, assisting the learning process.

MagLab implements *intelligent learning* through the use of *wizards* in order to simplify and de-skill the selection and use of appropriate analytical management techniques. This simplification enhances the learning process and reduces the prerequisite theoretical knowledge required by the user, making techniques available to a wider audience and providing a greater understanding in the application of techniques, as figure 3 illustrates.

## 4 CONCLUSIONS

The outstanding capabilities of the Tcl/Tk in creating GUIs were used in order to build a really fine tool for academic education: MagLab. It can be efficiently used for educational purposes as part of either an introductory or a more advanced course in Management Analytics. It is very easy to use MagLab and little time is required for its learning. The great variety of functions and options it includes, together with the detailed help topics provided directly by the interface of the tool, promote extremely the learning process and make working with MagLab both productive and enjoyable. The development of MagLab continues and more functions, techniques and algorithms are included, so that it becomes a really professional management tool.

## ACKNOWLEDGEMENTS

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# SPECIAL SESSION ON IT SOLUTIONS FOR HEALTHCARE

# Effect of Touch Care and Fomentation Use in Nursing Care
## *Examination from Fingertip Pulse*

Yoko Hirohashi[1], Chieko Kato[2], Shoko Minamiyama[2],
Hiroaki Hasegawa[2], Yoshiko Yuki[2] and Toshiko Sasaki[2]
[1]*Department of Nursing Education, Shoin University, Moronosato, Atsugi, Japan*
[2]*Department of Nursing Education, Nayoro City University, W4-N4, Nayoro, Japan*
*hirohashi@shoin-u.ac.jp, {chiekok, minamiyama, hasegawa, yuki777, sasaki-toshi}@nayoro.ac.jp*

Keywords: Touch care, Foot bathing, Fingertip pulse wave, Nursing care.

Abstract: Concerning the effectiveness of foot bathing and Touch Care as care-giving methods, verification was obtained by physiological data gathered from fingertip pulse and vital sign readings, as well as a survey questionnaire. In testing each care method, namely, carbonated water bathing, lower leg Touch Care, foot bathing, and foot bathing + Touch Care, readings were taken 3 times: before, immediately after, and 10 minutes after completion of the procedures. The results were as follows: These nursing cares showed effectiveness 77.8% - 90% of the cases. The various methods showed an improvement in participants' mood in the following order of effectiveness: foot bathing + Touch Care, Touch Care, carbonated water bathing, and foot bathing. When comparing only to foot bathing, foot bathing + Touch Care had a greater effectiveness in warming the body. Touch Care and foot bathing + Touch Care showed effectiveness in improving blood circulation, and carbonated water bathing showed effectiveness in warming the body without altering vital signs. The procedures' results showed the importance of applying these care techniques to the type of care most suitable for the subjects, and the importance of application in regard to support of mental health.

# 1 INTRODUCTION

## 1.1 Research Background and Purpose

Since the birth of nursing care as a specialized vocation in the 19th century, there has been a continual search to discover which techniques should be used to promote patients' vitality, advancement of rehabilitation processes, and the most beneficial means of achieving health of mind and body.

Nursing care related to cleanliness and comfort goes beyond the general concept of merely being clean or comfortable, but rather, involves the healing of disease, the discussion of effective means of pursuing good health, involving actual cases where disease conditions are improved by nursing care. Accordingly, this is not the product of coincidence, but rather by establishment of nursing care based on evidence of the effectiveness of intentional implementation of vocational nursing, and in order to propagate good nursing, there needs to be an examination of the scientific techniques of nursing care.

In 2013 we conducted research into the examination of the effectiveness of Touch Care (baby massage) involving mothers and their infants. Effectiveness with both mothers and their children was recognized, and in order to promote the advancement of baby massage, environment, timing, and related vocations were suggested as important factors.

Application of Touch Care is a simple and non-invasive care technique, and is an increasingly desirable technique on the nursing scene. At the same time, fomentation - the technique of applying hot compresses to warm the body - is also spoken of as a means of nursing care for the effective promotion of health and relief of pain in patients. Nurses can individually judge between the practice of these techniques, and can expect repeated effectiveness regarding comfort, health promotion, maintenance of cleanliness, improvement of general condition. Moreover, these are techniques which are implemented simply, without the need of reliance upon medical instruments. It can be said that these techniques should increasingly be introduced in medical institutions, elderly care facilities, and residential settings.

So far, initial research of the effectiveness of fomentation treatment and Touch Care has involved examination and understanding of autonomic nerve balance through testing of saliva, electromyogram, blood circulation, ECG, as well as EEG, and use of physiological indexes. This initial research has been productive, and the effectiveness of these care techniques has been definitely verified. However, up to this point, judging the value of the sense of contentment and mental healing for recipients of these care techniques has been limited to comments of the recipients' awareness, such as "It felt good", or "I felt comfortable". The objective examination of this kind of emotional effect remains the field of study for Touch Care and fomentation treatment research.

Our aim this time in research is an objective examination of the effects of fomentation treatment and Touch Care nursing care techniques by means of understanding emotional flexibility and good health from non-linear analysis of fingertip pulse fluctuations. At the same time, autonomic nerve balance will be measured, and effort will be made to grasp the influence of fomentation treatment and Touch Care upon the autonomic nervous system.

## 1.2 The Effect of Touch Care

While foot bathing as one type of fomentation Touch Care is defined as contact through massage, and has been described as a means of forming a bonding relationship between mother and child, the Hirohashi group, through results of infant fingertip pulse measurement, determined that "the infant's autonomic nervous system was under tension, relaxed immediately after application of the mother's Touch Care, and then 10 minutes after cessation of Touch Care returned to the prior tension". This led to the conclusion that by means of the parent's close contact during these fluctuations, bond formation with the infant was progressing.

There are reports that Touch Care, using light pressure and causing muscle relaxation, from the time massage begins, well-known emission of oxytocin is recognized, and at 10 minutes and again at 20 minutes after beginning massage, for a brief time oxytocin concentration roughly doubles. That is to say, with Touch Care oxytocin levels are a key factor.

Known effects of oxytocin are, 1) decrease in anxiety, and strengthening of sociability and child-rearing activities, 2) strengthening of "social memory", 3) action affecting tranquility and pain relief, 4) improvement of learning capacity, 5) reduction of blood pressure, 6) body temperature regulation (causing warmth to be transferred to other body parts, working like a thermostat), 7) regulation of digestive activity, 8) control of body fluids, 9) enhancement of growth, and injury healing.

The foot has a high level of nerve sensitivity, and by means of Touch Care, results such as reduction of peripheral blood vessel contraction, rise in temperature at sole of the foot, as well as feelings of comfort and physiological relaxation are obtained. This is due to vagus nerve activity, and operates on the following areas: control and stabilization of heartrate, blood pressure, and respiration rate, reduction of norepinephrine and epinephrine concentrations, reduction of stress-related cortisol reaction, provides a link to stress relief, and leads to stabilization of depression and anxiety in both body and mind. Furthermore, by means of muscle relaxation, stimulation of the digestive tract to encourage digestion, as well as advancement of serotonin secretion, growth rate of newborns and nursing infants is heightened, sleep activity is improved, and a smooth transition between sleep and awakening is clearly observed.

The Kato's group (2006), in order to ascertain the influence of cortisol on food intake, conducted a survey of Touch Care participants using samples of CgA found in saliva, reported that amounts of CgA in saliva decreased, and also reported that readings of middle finger surface blood vessels indicated dilation, and during contraction showed a reduction of blood pressure. These findings suggest that there is a "mutual response" effect between both the giver and the recipient of massage.

## 1.3 The Effects of Foot Bathing

In addition to the purpose of maintaining cleanliness, foot bathing has other experientially known effects, such as promotion of blood circulation, maintaining body warmth, relaxation and refreshment. Foot bathing methods have been the object of various research studies, examining ways to produce effective results. Foot bathing, by means of stimulating warmth, promotes expansion of blood vessels in the feet, increases body temperature at the surface of the feet, causes a significant increase of blood flow in the feet, and by warming the peripheral blood supply which circulates throughout the body, skin temperature of the upper limbs is elevated. Furthermore, through the influence of foot bathing, the following tendencies are revealed:

1) From the reflection of autonomic nerve activity, electrocardiogram wave-to-wave intervals

obtained from the chronological frequency analysis fluctuations in heartbeat affecting cardiac autonomic nerve activity.
2) High Frequency and Low Frequency/High Frequency analysis of rise/fall component from fluctuations in heartbeat.
3) From analysis of brain waves, observation of temporary fluctuations of tension in autonomic nerves.
4) Relaxation effect from control of sympathetic nervous system and increased activity of parasympathetic nervous system.

From subjective evaluation of the effects of warmth and pleasurable sensations, as a result of using Profile Of Mood States (POMS) and Visual Analog Scale (VAS), the following results were reported: trends of measured increase in levels of “vigor”, decreased levels of “fatigue” , an increase in responses of “the body is hot”/“the body is warm” . In addition, regardless of the lack of median temperature rise from bathing, it was clear that many participants expressed that their body core and extremities were warmer. Considering the psychological effect of an awareness that “I am warmer” being brought about, the stimulated sense of warmth signifies a meaningful connection to various effects of relaxation.

In recent years, carbonated spring water foot bathing has been used for medical treatment of ulcers and blockages from arteriosclerosis, and use of carbonated spring water to increase blood flow to the skin is clearly superior to that of fresh water bathing. The phenomenon of red-flushed skin of the feet when placed in carbonated spring water is considered to be related to the increase of blood flow due to dilation of the blood vessels in the skin, a result of prostaglandin E2 which strongly triggers blood vessel expansion. Furthermore, foot bathing in carbonated spring water has the effect of increasing blood circulation at the skin’s surface over the entire body, and shows significant benefits regarding muscle tension, improvement of joint motion, feelings of relaxation, as opposed to fresh water bathing. When viewing the above factors, carbonated spring water foot bathing appears to show a high degree of effectiveness of foot bathing.

Treatment and Touch Care (massage) are simple procedures, and while it is said that these care techniques produce significant amounts of emotional calming, the current status is that these techniques are not often implemented in the busy environments of hospitals and other facilities. If, through examination of data from fingertip pulse readings, it can be verified that fomentation treatment and Touch Care have a significant effect of improving the maintenance of mind and body wellness, we believe that its introduction and promotion in the medical and health care communities will be advanced.

### 1.4 Research Significance

While foot bathing as one type of fomentation treatment and Touch Care (massage) are simple procedures, and while it is said that these care techniques produce significant amounts of emotional calming, the current status is that these techniques are not often implemented in the busy environments of hospitals and other facilities. If, through examination of data from fingertip pulse readings, it can be verified that fomentation treatment and Touch Care have a significant effect of improving the maintenance of mind and body wellness, we believe that its introduction and promotion in the medical and health care communities will be advanced.

Also, even without being specifically directed by physicians, the scientific examination of the effectiveness of available fomentation treatment and Touch Care can connect and further the establishment and development of these techniques as areas of study in nursing education.

## 2 RESEARCH METHOD

### 2.1 Subjects of Survey

Nursing students and faculty members, who consented to participate, were the subject of this study. For each type of fomentation treatment and Touch Care experiment, approximately 10 people were chosen, with a plan of 40 people in all participating, but the actual results were obtained from the following: carbonated hot spring water foot bathing - 9 persons; lower leg Touch Care - 11 persons; foot bathing – 10 persons; foot bathing and Touch Care - 15 persons; Total - 45 participants. Subjects were as follows: Participants – 33 persons; male participants – 3 persons; female participants - 30; average age – 24.8years old.

### 2.2 Survey Period

January – March, 2015.

### 2.3 Survey Method

The following was addressed:

① foot bathing (hot water only, 10 minutes), ② foot bathing (hot water with carbonation added, 10 minutes. 40℃ with approx. 1000 ppm concentration of carbonic acid. Because carbonic acid concentration decreases as temperature increases, water was not able to be heated much.), ③ lower leg Touch Care (massage foot region / lower leg region / thigh region. Hand massage was applied for 2 - 4 times), ④ foot care with combined hot water foot bathing and Touch Care (10 minutes, 4 types of care were applied).

With each type of care, the participants' vital signs (body temperature, pulse, blood pressure), skin temperature (back of hand, base of thumb, top of foot, base of big toe, chest area, etc.), and fingertip pulse were measured at three intervals: before treatment, immediately following treatment, and 10 minutes after treatment. Fingertip pulse readings were obtained by measuring pulse fluctuations by means of installed computer software *LYSPECT*, and each reading measured the pulse for 3 minutes. Upon completion of measurement readings for all participants, all data was analyzed for study. Concerning the analysis method, non-linear / SPSS analysis with computer software *LYSPECT* was used. At the same time, the participants were asked to complete a questionnaire related to their mood and level of contentment as a result of the treatment, and that data was combined with the physical test data for comparison.

3 types of questionnaire were prepared. The 1st type showed a 20 - step face scale (Fig.1), and prior to treatment asked the subject to give their own assessment, placing a circle around the number of the face that most closely resembled their mood. The 2nd type of questionnaire used the same face scale, and asked the participant to indicate their mood immediately following treatment, and also at the the conclusion of the experiment. The 3rd type of questionnaire asked the participant to indicate their overall mood regarding the treatment, and in what kind of scenario would they choose to receive this kind of treatment again.

Moreover, for lower leg Touch Care and Touch Care while receiving foot bathing treatment, one person with proficiency in these techniques was placed in charge of the group, so as to maintain uniformity of technique as much as possible.

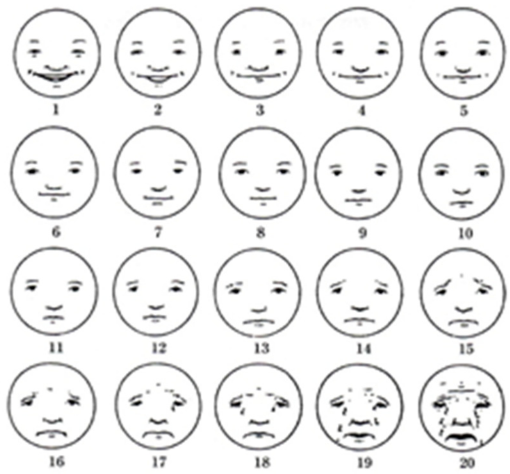


Figure 1: Face scale.

## 2.4 Method of Analysis

For each type of care treatment, regarding the readings of variations in body temperature, pulse, blood pressure, and skin surface temperature, the degree of rise and fall of the numerical values was analyzed. Concerning fingertip pulse, as an indicator of mental adaptability (wellness), if the Largest Lyaponov Exponent (LLE) numerical value showed an increase, it was judged that treatment was effective. When determining whether the sympathetic nerve or parasympathetic nerve was superior, if autonomic nerve balance (ANB) values were near to a precisely good balance, or if the parasympathetic nerve showed superiority, and it was observed that the participant was in a relaxed state, it was judged that the care treatment was effective.

On the questionnaire, numerical values were assigned to variations in response on the face scale, showing the difference in participants' moods before and after treatment, and numerical ranking was assigned to the answers given regarding mood fluctuations and their associated stimuli.

# 3 RESULTS

## 3.1 Subject of Research / Location

27 students and 5 faculty members from the nursing education department of N University participated as test subjects. Of these, 3 were male and 29 were female. The subject numbers for each type of test were as follows: Carbonated water foot bathing - 9 persons, Touch Care - 11 persons, Foot bathing - 10

persons, Foot bathing + Touch Care - 15 persons. Testing was conducted in the training lab of the N University nursing department; the subjects' vital signs, skin temperature, and fingertip pulse readings were measured before and after the Care application sessions. Room temperature was 21 - 22 ℃. Temperature of the water used for foot bathing was 40 ℃. For the carbonated water foot bath and regular foot bath tests, subjects' feet were placed in water for 10 minutes. For subjects participating in foot bathing + Touch Care, during the 10 minutes feet were in the water, the subject's feet were washed with soap and massaged. For those being tested with lower leg Touch Care, the feet / lower legs / thighs / upper thigh areas were massaged.

## 3.2 Test Measurement Results

### 3.2.1 Fingertip Pulse Values

Results showed that LLE values rose, and mental activity was stimulated; ANB values arrived at a good balance, and parasympathetic nerve activity was dominant, indicating a relaxing effect. (Fig.2).

#### 3.2.1.1 Carbonated Water Bath

Testing showed that carbonated water bath care was effective in 77.8% of test subjects (7 out of 9 persons), and ineffective in 22.2% (2 out of 9 persons) of the subjects. Of this group, results showing subjects experiencing effective mental activity stimulation were 71.4% (5 out of 7 persons), and those showing signs of relaxation were 28.6% (2 out of 7 persons), as depicted in Fig. 3.

#### 3.2.1.2 Lower Leg Touch Care

Those recipients showing effectiveness were 90.9% (10 out of 11 persons), and those showing non-effectiveness were 9.1% (1 out of 11 persons). Of these, results showing subjects experiencing effective mental activity stimulation were 30.0% (3 out of 10 persons), and those showing signs of relaxation were 70.0% (7 out of 10 persons), as depicted in Fig. 4.

| Carbonated foot-bath | | | |
|---|---|---|---|
| No.1 | LLE↓ | ANB→ | × |
| 2 | LLE↑ | ANB↑ | ○ |
| 3 | LLE↑ | ANB↓ | ○ |
| 4 | LLE↓ | ANB↑ | × |
| 5 | LLE↑ | ANB↓ | ○ |
| 6 | LLE↑ | ANB↓ | ○ |
| 7 | LLE↑ | ANB↑ | ○ |
| 8 | LLE↑ | ANB↑ | ○ |
| 9 | LLE↑ | ANB↑ | ○ |
| Touch care | | | |
| 10 | LLE→ | ANB↓ | ○ |
| 11 | LLE→ | ANB→ | × |
| 12 | LLE↑ | ANB↓ | ○ |
| 13 | LLE↑ | ANB↓ | ○ |
| 14 | LLE↑ | ANB↓ | ○ |
| 15 | LLE↑ | ANB↑ | ○ |

| Touch care | | | |
|---|---|---|---|
| 16 | LLE↑ | ANB↓ | ○ |
| 17 | LLE↑ | ANB↓ | ○ |
| 18 | LLE↑ | ANB↓ | ○ |
| 19 | LLE↑ | ANB↓ | ○ |
| 20 | LLE↑ | ANB↓ | ○ |
| Foot bathing | | | |
| 21 | LLE↑ | ANB↑ | ○ |
| 22 | LLE↑ | ANB↑ | ○ |
| 23 | LLE↓ | ANB↓ | ○ |
| 24 | LLE↑ | ANB↑ | ○ |
| 25 | LLE↓ | ANB→ | × |
| 26 | LLE↓ | ANB↓ | ○ |
| 27 | LLE↓ | ANB↑ | × |
| 28 | LLE↑ | ANB↓ | ○ |
| 29 | LLE↑ | ANB↓ | ○ |
| 30 | LLE↑ | ANB↓ | ○ |

| Touch care +Foot bathing | | | |
|---|---|---|---|
| 31 | LLE↑ | ANB→ | ○ |
| 32 | LLE↓ | ANB↓ | ○ |
| 33 | LLE↓ | ANB↑ | × |
| 34 | LLE↑ | ANB↓ | ○ |
| 35 | LLE↑ | ANB↓ | ○ |
| 36 | LLE↓ | ANB↑ | × |
| 37 | LLE↑ | ANB↓ | ○ |
| 38 | LLE↑ | ANB↓ | ○ |
| 39 | LLE↑ | ANB↑ | ○ |
| 40 | LLE↑ | ANB↑ | ○ |
| 41 | LLE↑ | ANB↑ | ○ |
| 42 | LLE↑ | ANB↓ | ○ |
| 43 | LLE↑ | ANB↓ | ○ |
| 44 | LLE→ | ANB↓ | ○ |
| 45 | LLE↑ | ANB↓ | ○ |

Figure 2: The effect of LLE and ANB.

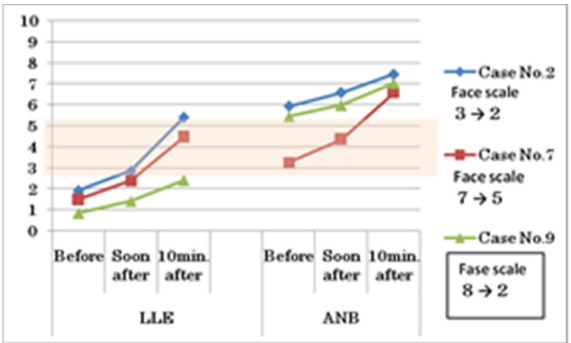


Figure 3: LLE rise (active) of carbonated water bathing.

#### 3.2.1.3 Foot Bathing

Those recipients showing effectiveness were 90.0% (9 out of 10 persons), and those showing non-effectiveness were 10.0% (1 out of 10 persons). Of these, results showing subjects experiencing effective mental activity stimulation were 33.3% (3 out of 9 persons), and those showing signs of relaxation were 66.7% (6 out of 9 persons), as depicted in Fig. 5.

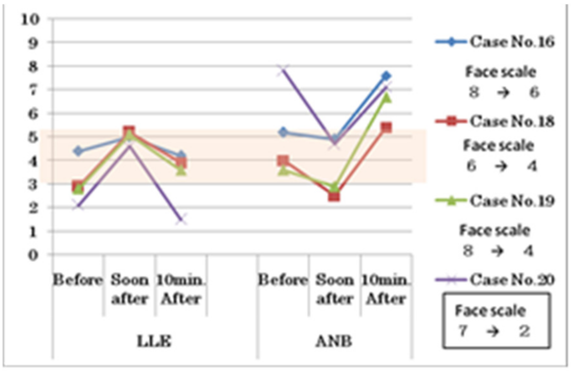


Figure 4: ANB down (relax) of Touch care.

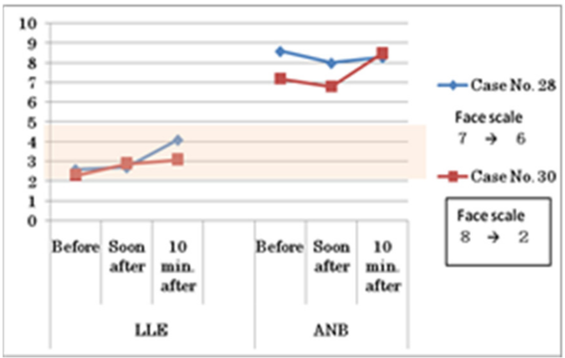


Fig.5: ANB slightly down (relax) of Foot bathing.

### 3.2.1.4 Foot Bathing + Touch Care

Those recipients showing effectiveness of foot bathing + Touch Care were 86.7% (13 out of 15 persons), and those showing non-effectiveness were 13.3% (2 out of 15 persons). Of these, results showing subjects experiencing effective mental activity stimulation were 38.5% (5 out of 13 persons), and those showing signs of relaxation were 61.5% (8 out of 13 persons), as depicted in Figure 6.

The overall results from the 4 different Care procedures were as follows: responses showing effectiveness were 86.7% (39 out of 45 persons), and those showing non-effectiveness were 13.3% (6 out of 45 persons).

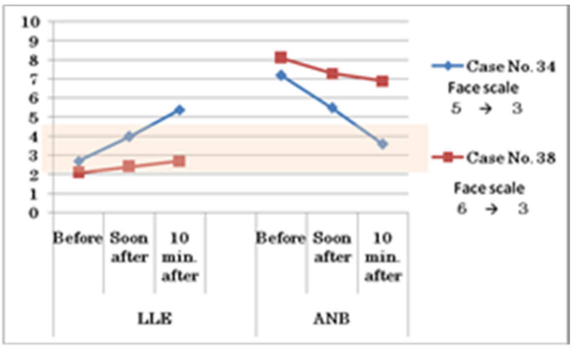


Figure 6: LLE rise ANB down (active and also relax) of Foot bathing + Touch care.

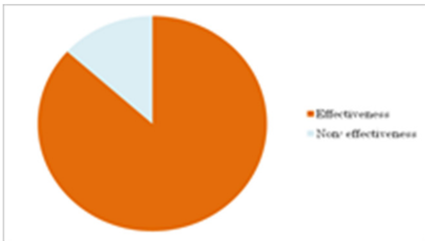

Figure 7: Effectiveness (= 86.7%).

## 3.2.2 Skin Temperature and Blood Pressure / Pulse Fluctuations

### 3.2.2.1 Carbonated Water Bath

Temperature readings of the eardrum, chest area, back of the hand, thumb, top of the foot, and big toe all showed a significant rise immediately following carbonated water bathing, and the eardrum temperature still showed an elevated reading 10 minutes after bathing. There were no indications of change in blood pressure or pulse readings.

### 3.2.2.2 Lower Leg Touch Care

The eardrum temperature showed a rise immediately after the procedure, as well as at 10 minutes afterward. Blood pressure and pulse readings both indicated lower readings immediately after the procedure and at 10 minutes afterward.

### 3.2.2.3 Foot Bathing

The chest area, back of the hand, top of the foot, and big toe temperature readings showed a rise immediately following testing, and only the chest area showed an increased temperature reading at 10 minutes afterward. However, the eardrum temperature showed no elevation. Blood pressure and pulse readings were lower immediately following the procedure, and at 10 minutes afterward an elevated fluctuation was observed.

#### 3.2.2.4 Foot Bathing + Touch Care

The eardrum, chest area, back of the hand, thumb, top of the foot, and big toe temperature readings all showed a significant rise immediately following foot bathing + Touch Care. Also, the eardrum, chest area, back of the hand, and thumb temperatures continued to be elevated 10 minutes afterward. Blood pressure readings were lower immediately after the procedure, as well as 10 minutes later. Pulse readings were lower immediately following testing, but rose 10 minutes later.

### 3.2.3 Questionnaire

#### 3.2.3.1 Face Scale

Of the 45 participants, 42 persons indicated on the face scale (by selecting a smiling face) that they felt an improvement to their mood after the Care procedure, as compared to how they felt prior to the experiment. After completing the procedure, 3 respondents the selected same face on the scale that they had chosen prior to the experiment (indicating no improvement in mood). However, these 3 persons all had fingertip pulse data that judged the Care procedure as ineffective in their cases. Also, with these 3 persons, the comparative breadth of overall mood improvement suggested that they initially began the experiment in a negative mood, as depicted in Fig. 8 and Fig. 9.

#### 3.2.3.2 Application of the Care

On the questionnaire, participants were asked to indicate in what scenarios they would be inclined to utilize the Care procedure they had received.

From the participants' accounting of the results, the content was divided in order of "sub-category", "category", and "core category", and thus core factors were extracted. Numerous respondents indicated that carbonated water bathing as a type of care which results in improvement of blood circulation, and care that supports a person's mental aspect, would be desirable. With Touch Care, numerous respondents recorded that they felt that its implementation helped their overall mental state, followed by relief from fatigue and improvement in blood circulation. With foot bathing and foot bathing + Touch Care, respondents indicated a support of mental state, and an improvement in body warmth from feeling chilled.

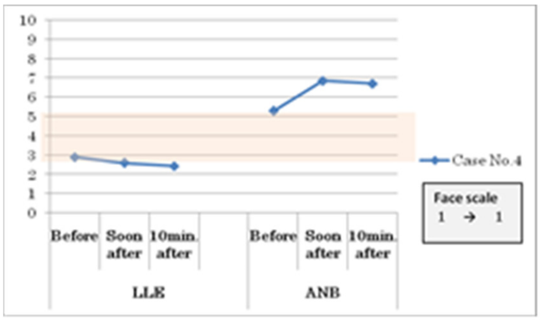


Figure 8: Non-effectiveness and no change on the face scale (Case No.4 : Carbonated water bath).

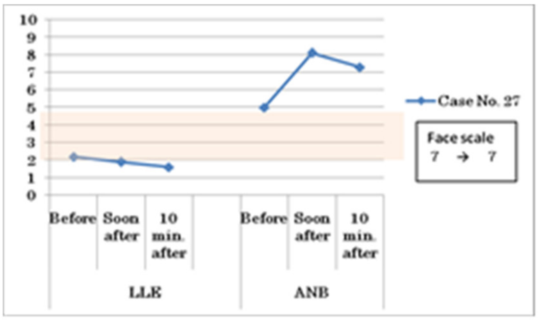


Figure 9: Non-effectiveness and no change on the face scale (Case No.27: Foot bathing).

## 4 CONSIDERATION

### 4.1 Considerations from Results of Fingertip Pulse Measurements

Analysis of LLE and ANB values taken from fingertip pulse readings yielded the following results: carbonated water bathing showed 80% effectiveness, and Touch Care / foot bathing / foot bathing + Touch Care all showed 90% effectiveness. Using data gathered from physiological information, it was judged that these procedures are effective as methods of nursing care. From prior research, it is believed that the methods used in this experiment are effective as an aid to healing. However, carbonated water bathing showed an activated effectiveness, and in proportion to the other methods of Touch Care, foot bathing, and foot bathing + Touch Care, it showed a high degree of effectiveness in bringing about relaxation, and showed a unique pattern different than the others. For this reason, it became apparent that in order to select the most suitable care for individual subjects, assessment of whether the subject feels cold, and observation of their current state of mind and overall body condition must be carefully noted. It was also determined that it is good to give the subject an explanation of the effects from each kind of care, and allow the subject to choose the type of care most desirable to them.

## 4.2 Considerations from Vital Signs Data

From body temperature readings, it was observed that, excluding foot bathing, the methods of carbonated foot bathing / Touch Care / and foot bathing + Touch Care all brought about a significant rise in core body temperature. The procedure results showed an influence upon the body with dilation of peripheral blood vessels, and a rise in temperature measured on the sole of the foot. With the foot bath, body surface temperature rose briefly, but there was no change detected in core body temperature. With carbonated water bath, the carbonic acid stimulation upon the skin surface influenced a rise in body temperature, resulting in a significant rise in core body temperature.

Blood pressure and fingertip pulse values showed a significant decrease as a result of Touch Care, and foot bathing + Touch Care. These techniques would be useful for situations when desiring to control improvement of blood flow. Because carbonated water bath did not bring about a change in blood flow, this technique could be implemented in situations where changes affecting blood circulation are undesirable. That is to say, this technique demonstrated the positive trait of maintaining temperature with no burden that would affect core body temperature.

## 4.3 Considerations from Face Scale Questionnaire Results

In the following order, Touch Care + foot bath, Touch Care, carbonated water bath, and footbath showed a high proportion of causing an improvement in mood, and from subjects' selection of a smiling face, an effect showing change in mental attitude was observed. It is hoped that there will be an active application of these care techniques tailored to the condition of subjects who desire to see an improvement in their frame of mind. In particular, the results suggest that through these care techniques, subjects who are experiencing a depressed frame of mind can see an effective improvement in their mood/frame of mind, as depicted in Fig.10-13.

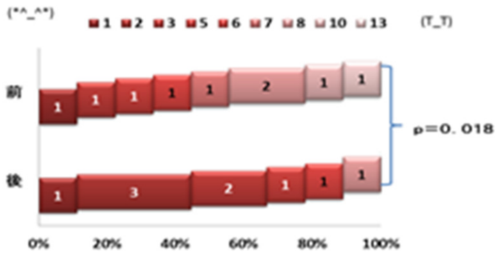


Figure 10: The change of Face scale in case of Carbonated water bath.

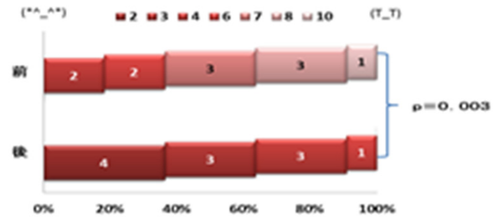


Figure 11: The change of Face scale in case of Touch care.

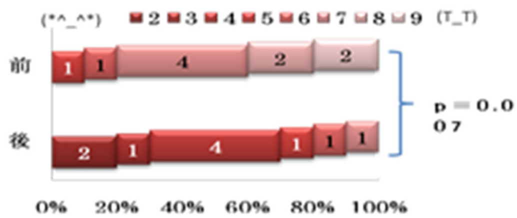


Figure 12: The change of Face scale in case of Foot bathing.

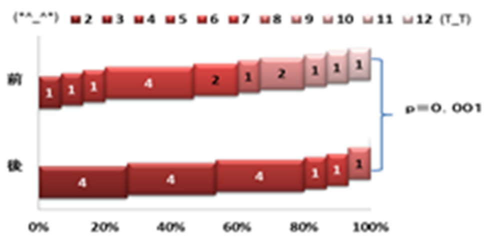


Figure 13: The change of Face scale in case of Foot bathing + Touch care.

In cases where the face scale indicated no change in mood, because physiological indicators LLE and ANB also showed no recognizable effect, the data suggest that the resulting effects of the care techniques served as barometer in revealing the mind state of the participants. The importance of grasping the effectiveness by evaluating mood changes following the care procedures was clearly seen.

### 4.4 Considerations from Results of the Questionnaire (Applicable Scenarios)

The 4 care techniques had in common the following result contents that showed scenarios where useful application could be expected: support of the psychological aspect, improvement in blood circulation, improvement regarding factors involving fatigue and lack of body warmth, and aid to sleep inducement. Especially noted was that carbonated water bathing, as a care method helpful to blood circulation, was useful for bedridden subjects prone to blood clots (thrombosis), and Touch Care was effective for improvement of fluid retention (edema) in the lower legs. The research suggested the importance of selecting the optimal method of care, most fitting to the subjects' condition and vital signs.

## 5 CONCLUSIONS

1. From results of fingertip pulse measurements, carbonated water bathing was seen to have an approximately 80% effectiveness. Touch Care, foot bathing, and foot bathing + Touch Care demonstrated an approximately 90% effectiveness.
2. From LLE and ANB data, in care techniques that are said to have healing properties, carbonated water bathing revealed an effectiveness in activation, while Touch Care, foot bathing, and foot bathing + Touch Care showed a proportionally high level of induced relaxation, and a pattern of effectiveness was unmistakably evident.
3. In cases where there was no change in mood, effectiveness was also undetectable in results from LLE and ANB physiological data.
4. In the following order, foot bathing + Touch Care, Touch Care, carbonated water bathing, and foot bathing all showed effectiveness in mood improvement.
5. When comparing foot bathing and foot bathing + Touch Care, foot bathing + Touch Care showed a higher effectiveness in warming the body.
6. Both Touch Care and foot bathing + Touch Care showed an effectiveness in improving blood circulation, and carbonated water bathing showed an effectiveness in warming the body without altering vital signs.

From the above findings, it is considered that selection of the most suitable nursing care for each subject, as well as its application, are important. Also, regarding care that provides mental health support, for reliable construction of a direct link of that care with proper subjects, it is our desire to see that applications of these care techniques be enthusiastically applied in both clinical settings and in everyday life.

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# SPECIAL SESSION ON INTELLIGENT APPLICATIONS OF INTERCRITERIA DECISION MAKING ANALYSIS

# InterCriteria Software Design: Graphic Interpretation within the Intuitionistic Fuzzy Triangle

Deyan Mavrov[1], Irina Radeva[2], Krassimir Atanassov[3], Lyubka Doukovska[2] and Ivan Kalaykov[4]

[1]*Prof. Dr. Asen Zlatarov University*
*1 Prof. Yakimov Blvd., 8010 Burgas, Bulgaria*
*dg@mavrov.eu*

[2] *Institute of Information and Communication Technologies, Bulgarian Academy of Sciences*
*Acad. G. Bonchev str., bl. 2, 1113 Sofia, Bulgaria*
*iradeva@iit.bas.bg, doukovska@iit.bas.bg*

[3] *Institute of Biophysics and Biomedical Engineering, Bulgarian Academy of Sciences*
*Acad. G. Bonchev str., bl. 105, 1113 Sofia, Bulgaria*
*krat@bas.bg*

[4] *Örebro University, School of Science and Technology*
*SE-701 82 Örebro, Sweden*
*ivan.kalaykov@oru.se*

Keywords: InterCriteria Analysis, Software design, Software implementation, Intuitionistic fuzzy sets, Index matrix.

Abstract: The InterCriteria Analysis (ICA) method offers an interesting new way for pairwise comparison of criteria among a set of criteria, against which a set of objects have been evaluated. This has been designed as a completely data driven method, which requires real data to practically see effect of its application.

A specialized software application has been developed, which requires as input one two-dimensional array of data of the evaluation of the set of *m* objects against the set of *n* criteria, and after processing returns as output two $n \times n$ tables, the first of which contains the membership parts, and the second – the non-membership parts of the intuitionistic fuzzy pairs that define the degrees of correlation between any two criteria in the set of criteria. Having presented the implementation of the basic ICA algorithm in (Mavrov, 2015), we present here a recently developed additional feature for graphical interpretation of the results of ICA, plotted as points in the Intuitionistic Fuzzy Interpretational Triangle, which reflects in the software application the new theoretical developments of the ICA approach, as discussed in (Atanassova, 2015).

## 1 INTRODUCTION

The novel InterCriteria Analysis (ICA) method was proposed in (Atanassov, et al, 2014) and significantly developed in a series of publications, including (Atanassova, et al, 2014a, 2014b, 2014c), (Atanassova, 2014) and others in (InterCriteria Research Portal, 2015).

Along with its theoretical development and search of testing datasets for approbation and application of the approach, intensive work has started on the software implementation of the ICA. In (Atanassova, 2015) the basic algorithm's implementation has been presented, and here we continue with presentation of a new phase of development of the ICA software, using functionalities for graphic output and human-machine interaction with the ICA results.

The ICA offers an interesting new way for comparison of the individual criteria among a set of criteria, against which a set of objects have been evaluated. This has been designed as a completely data driven method, which requires real data to practically see effect of its application. The algorithm, and the software application, require as input one two-dimensional array of data of the evaluations, or measuring, of a set of $m$ objects against a set of $n$ criteria. As a result of application of the algorithm, we expect a new table, $n \times n$, which contains intuitionistic fuzzy pairs that define for each pair of criteria the degree of membership and non-membership of the IF correlation between the two criteria in the pair of criteria. In our implementation, for the needs of more handy operation, the result is returned in the form of two output $n \times n$ tables, the first of which contains only the membership parts, and the second one – only the non-membership parts of these Intuitionistic fuzzy pairs.

## 2 LANGUAGE AND LIBRARIES

For reader's convenience, here we will again, after (Mavrov, 2015), present the basic prerequisites for the software application: the programming language and the libraries that have been employed in the process of development.

The application is developed using the C++ programming language. The development environment is Microsoft Windows. For compiler, the standard programme CL.exe from the Visual C++ 2012 has been used, without using the Visual Studio graphic environment.

Based on previous experience, the *Qt* library was chosen for the application's graphical interface. *Qt* offers classes, which help building the on-screen graphic objects, as well as classes for non-graphic objects like (strings, database connections, etc.). Each *Qt* class object can interact with the rest objects, using a system of signals and slots, and sending a signal from one object can be connected to another object's slot. The *Qt* library is cross-platform library, which works with a variety of operating systems and compilers, and in case that only the standard *Qt* classes are used, an application designed under Windows, can get compiled under Linux with almost no changes. Moreover, the *Qt* project includes a C++ program development environment, *Qt* Creator. It offers a visual editor for design of windows, which significantly facilitates the use of the graphic interface.

The remaining important details of the basic software implementation, like format of the input data, the design of the main module of the program, basic functionalities like reading of the input data, processing of these data and calculation of the IF values, as well as the output of the result, have been discussed in details in (Mavrov, 2015) and will not be repeated here.

## 3 MODULE FOR *ICA* RESULTS' GRAPHIC VISUALIZATION

The *Qt* library allows working with two dimensional graphics, by using the classes *QGraphicsView* and *QGraphicsScene*. They allow on screen visualization of various forms and shapes, using lines, circles and other objects. For this aim, in a new class for window, called *IFS_Triangle*, an object from the new class *IFS_GraphicsView* is being imported, which inherits *QGraphicsView*. Creating own inheriting class for the graphic window, allows higher flexibility in drawing the objects. The graphic window opens after clicking on the 'Graphic' button.

The visualization of the results obtained after applying the ICA algorithm over input data, requires us to use the intuitionistic fuzzy triangle, see (Atanassov, 1989), (Atanassov, 1999), (Atanassov, 2012). It is a triangle from the Euclidean place, with vertices (0, 0), (1, 0) and (0, 1), where the intuitionistic fuzzy membership part $\mu$ is plotted along the abscissa, and the non-membership part $\nu$ – is plotted along the ordinate. Thus, the maximal value for each of these variables is 1, with the classical 'Truth' being plotted into the (1, 0) point, and the classical 'Falsity' being plotted into the (0, 1) point, while the (0, 0) point stands for the complete Uncertainty.

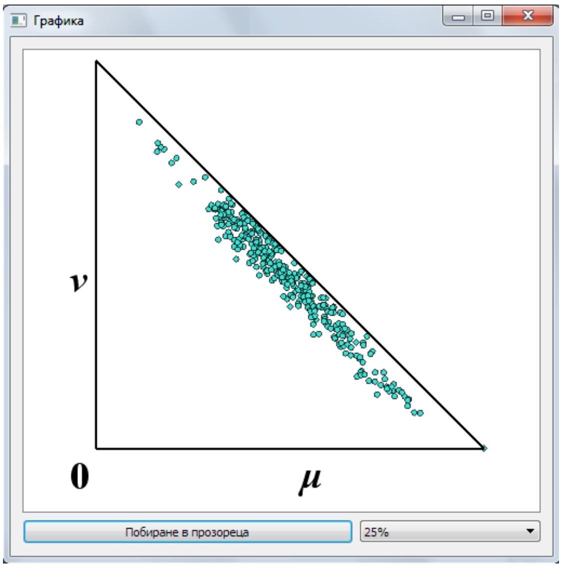



Figure 1: Graphics of the points, staying for the intuitionistic fuzzy pairs of InterCriteria consonances.

The triangle (see Figure 1) is being rendered using the embedded class *QGraphicsPolygonItem*, which is intended for plotting polygons. There are also classes for visualization of points, but in expected cases of multiple points (which will significantly load the memory), the points are directly drawn onto the background of the graphic window. The duplicating points are removed in advance, for the aim of improving the performance. The drawing itself is controlled by the class of the central window, since there are the input and output data stored.

The graphic window permits scaling. Moreover, if we want to check which pairs of criteria form a given point, or a given area of points from the IF triangle, we can drag with the mouse a rectangular area around the desired points, as shown in Figure 2.

After this selection has been made, a pop-up window appears with the names of the detected points, i.e. pairs of criteria, as well as the values of their coordinates, the IF membership and non-membership factors.

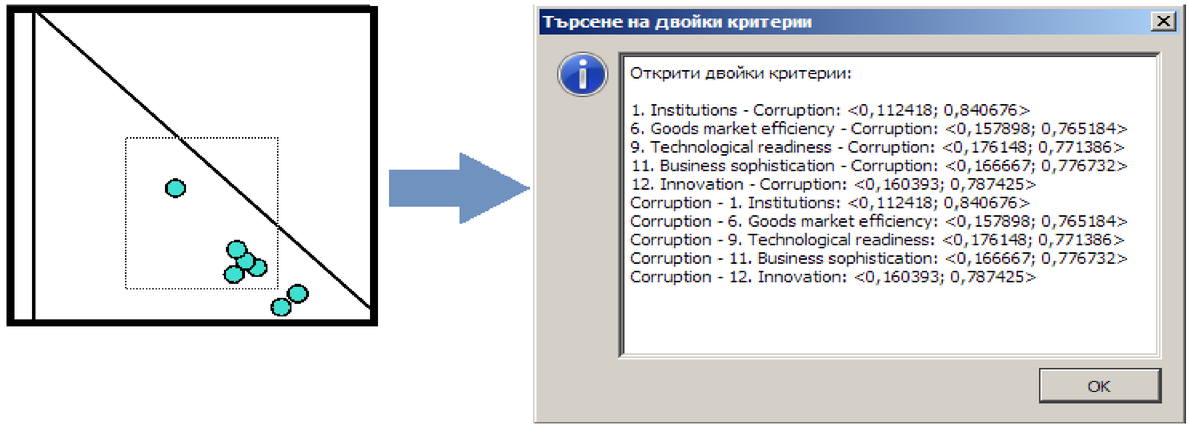



Figure 2: Search for pairs of criteria, using the graphic visualization of the ICA results.

On the other hand, it can be sometimes useful to draw the lines that connect a point in the IF triangle, with the triangle's vertices, together with calculation the distances of that point from the three vertices. This option is activated with the button 'Distance from vertices', as presented in Figure 3.

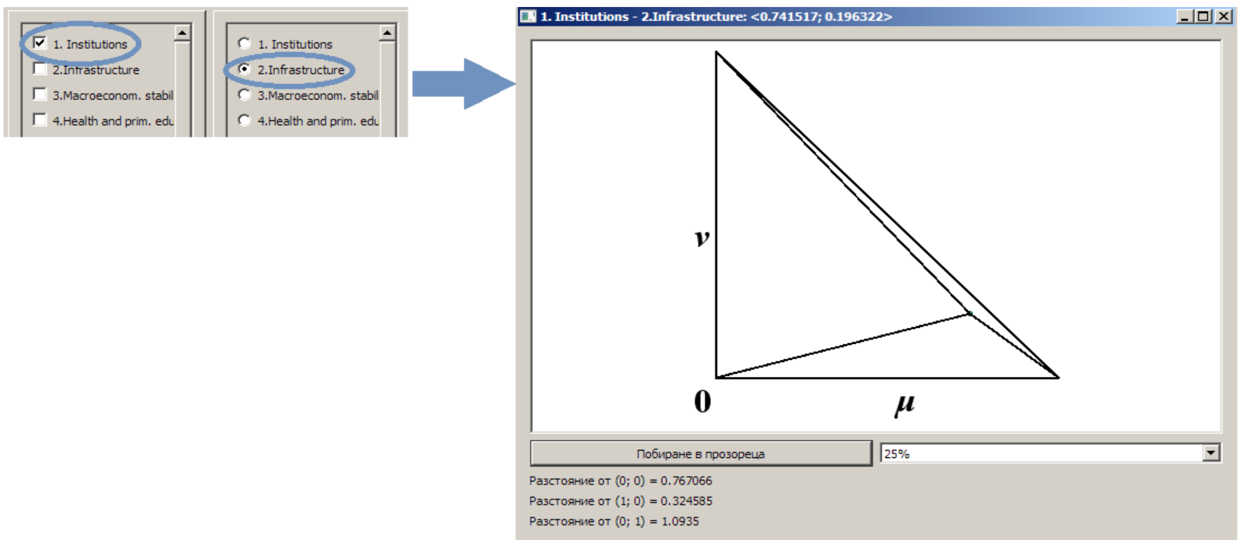
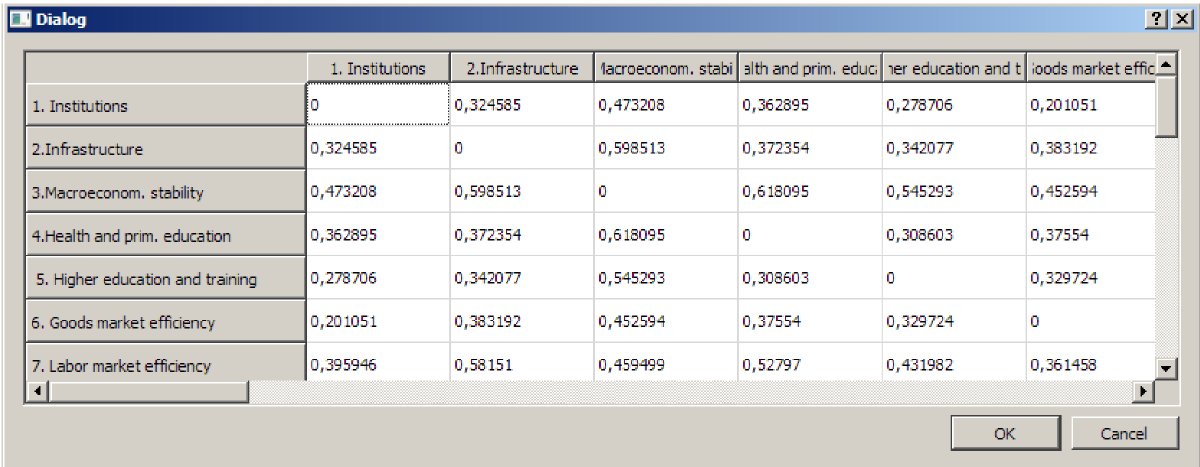



Figure 3: Rendering a point and its distances from the three vertices of the IF triangle.

For this aim, it is necessary to pre-select two criteria, whose InterCriteria consonance, in the form of an IF pair, will determine the coordinates of the point. The utilized graphic window here is the same, with additional lines connecting the point with the vertices, and the calculated distances. If this view does not give enough information, the program includes options that provide an overview of all distances from all InterCriteria points to the triangle's vertices, as presented in tables related to each vertex. These tables are opened via a separate window using the buttons 'Distance from [vertex coordinates]' in the main window. To save time, the values here are calculated in real time only for the visible cells from the table. The table of distances from (1, 0) is illustrated in Figure 4.




| | 1. Institutions | 2.Infrastructure | lacroeconom. stabi | alth and prim. educ | ner education and t | ioods market effic |
|---|---|---|---|---|---|---|
| 1. Institutions | 0 | 0,324585 | 0,473208 | 0,362895 | 0,278706 | 0,201051 |
| 2.Infrastructure | 0,324585 | 0 | 0,598513 | 0,372354 | 0,342077 | 0,383192 |
| 3.Macroeconom. stability | 0,473208 | 0,598513 | 0 | 0,618095 | 0,545293 | 0,452594 |
| 4.Health and prim. education | 0,362895 | 0,372354 | 0,618095 | 0 | 0,308603 | 0,37554 |
| 5. Higher education and training | 0,278706 | 0,342077 | 0,545293 | 0,308603 | 0 | 0,329724 |
| 6. Goods market efficiency | 0,201051 | 0,383192 | 0,452594 | 0,37554 | 0,329724 | 0 |
| 7. Labor market efficiency | 0,395946 | 0,58151 | 0,459499 | 0,52797 | 0,431982 | 0,361458 |

Figure 4: Distances of all points from the vertex (1, 0) of the triangle.

## 4 CONCLUSION

The aim of this paper is to describe the software design and implementation of one important aspect of the theory of ICA which has been recently developed theoretically (Atanassova, 2015), and was shown to provide an alternative, and in some situations better analysis of the results of the ICA.

Discussing the software implementation of the ICA approach is considered by our team important, because this allows reproducibility of the results, obtained with the ICA method.

If necessary, other functionalities are also possible, among which selection of consonance thresholds, in order to sieve the criteria that are in highest positive consonance with each other. In the present form, the application can be successfully used for analysis of new data, for detecting known correlations, and discovery of new, previously unknown correlations and knowledge.

## ACKNOWLEDGEMENTS

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# InterCriteria Analysis Applied to Various EU Enterprises

Lyubka Doukovska[1], Vassia Atanassova[2], George Shahpazov[1] and František Čapkovič[3]

[1] *Institute of Information and Communication Technologies, Bulgarian Academy of Sciences*
*Acad. G. Bonchev str., bl. 2, 1113 Sofia, Bulgaria*
*doukovska@iit.bas.bg, atlhemus@abv.bg*

[2] *Institute of Biophysics and Biomedical Engineering, Bulgarian Academy of Sciences*
*Acad. G. Bonchev str., bl. 105, 1113 Sofia, Bulgaria*
*vassia.atanassova@gmail.com*

[3] *Institute of Informatics, Slovak Academy of Sciences*
*Dubravska cesta 9, 845 07 Bratislava, Slovak Republic*
*Frantisek.Capkovic@savba.sk*

Keywords: InterCriteria decision making, Intuitionistic fuzzy sets, Index matrix, European enterprises, Micro, small, medium and large enterprises in EU27, Positive consonance.

Abstract: The present research aims to detect certain correlations between four economic indicators, against which have been evaluated the economic entities of the European Union with 27 Member States, as split into four categories: micro, small, medium and large enterprises. The mathematical formalism employed for revealing these dependencies, particularly termed here 'positive' and 'negative consonances', is a novel decision support approach, called InterCriteria Analysis, which is based on the theoretical foundations of the intuitionistic fuzzy sets and the augmented matrix calculus of index matrices. The proposed approach can be useful in processes of decision making and policy making, and it can be seamlessly integrated and further extended to other related application areas and problems, where it is reasonable to seek correlations between a variety of economic and other indicators.

## 1 INTRODUCTION

In present work, we make the consequent step in a series of research, aimed at proposing the application of the novel approach of InterCriteria Analysis (ICA) to economic data, aimed at the discovery of correlations between important economic indicators, based on available economic data. At this new step, we take as input information about the economic enterprises in the EU27, the European Union with 27 Member States, as grouped in the four types of enterprises with respect to the scale: micro, small, medium and large enterprises, (Calogirou, et al., 2010).

The indicators against which these four types of EU27 enterprises have been evaluated are four, namely: 'Number of enterprises', 'Number of persons employed', 'Turnover' and 'Value added at factor cost'. Potential discovery of correlations (in this approach termed as *positive consonances*) between economic indicators can bring new knowledge and improve decision making and policy making processes.

The ICA approach is specifically designed for datasets comprising evaluations, or measurements of multiple objects against multiple criteria. In the initial formulation of the method, the aim was to detect correlations between the criteria, in order to eliminate future evaluations/measurements against some of the criteria, which exhibit high enough correlations with others. This might be the desire, when some of the criteria are for some reason deemed unfavourable, for instance come at a higher cost than other criteria, are harder, more expensive and/or more time consuming to measure or evaluate. Elimination or reduction of these unfavourable criteria from the future evaluations or measurements may be desirable from business point of view in order to reduce cost, time or complexity of the process.

This paper is organized as follows. The basic mathematical concepts employed in the ICA method are presented in Section 2. In Section 3, we present the input data and the results of their processing. We report of the findings, produced by the algorithm and formulate our conclusions in the last Section 4.

## 2 INTERCRITERIA ANALYSIS METHOD

The building blocks of the presented InterCriteria Analysis for decision support are the two concepts of intuitionistic fuzziness and index matrices.

Intuitionistic fuzzy sets defined by Atanassov (Atanassov, 1983; Atanassov, 1986; Atanassov, 1999; Atanassov, 2012) are one of the most popular and well investigated extensions of the concept of fuzzy sets, defined by Zadeh (Zadeh, 1965). Besides the traditional function of membership $\mu_A(x)$ defined in fuzzy sets to evaluate the membership of an element $x$ to the set $A$ with a real number in the [0; 1]-interval, in intuitionistic fuzzy sets (IFSs) a second function has been introduced, $\nu_A(x)$ defining respectively the non-membership of the element $x$ to the set $A$, which may coexist with the membership function. More formally the IFS itself is formally denoted by:

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle \mid x \in E\},$$

and the following conditions hold:

$$0 \le \mu_A(x) \le 1,\ 0 \le \nu_A(x) \le 1,$$
$$0 \le \mu_A(x) + \nu_A(x) \le 1.$$

Multiple relations, operations, modal and topological operators have been defined over IFS, showing that IFSs are a non-trivial extension of the concept of fuzzy sets.

The second concept, on which the proposed method is based, is the concept of index matrix, a matrix which features two index sets. The basics of the theory behind the index matrices is described in (Atanassov, 1991), and recently developed further on in (Atanassov, 2014).

In the ICA approach, the raw data for processing are put within an index matrix $M$ of $m$ rows $\{O_1, \dots, O_m\}$ and $n$ columns $\{C_1, \dots, C_n\}$, where for every $p$, $q$ $(1 \le p \le m,\ 1 \le q \le n)$, $O_p$ in an evaluated object, $C_q$ is an evaluation criterion, and $e_{O_pC_q}$ is the evaluation of the $p$-th object against the $q$-th criterion, defined as a real number or another object that is comparable according to relation $R$ with all the rest elements of the index matrix $M$.

$$M = \begin{array}{c|ccccccc} & C_1 & \cdots & C_k & \cdots & C_l & \cdots & C_n \\ \hline O_1 & e_{O_1,C_1} & \cdots & e_{O_1,C_k} & \cdots & e_{O_1,C_l} & \cdots & e_{O_1,C_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ O_i & e_{O_i,C_1} & \cdots & e_{O_i,C_k} & \cdots & e_{O_i,C_l} & \cdots & e_{O_i,C_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ O_j & e_{O_j,C_1} & \cdots & e_{O_j,C_k} & \cdots & e_{O_j,C_l} & \cdots & e_{O_j,C_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ O_m & e_{O_m,C_1} & \cdots & e_{O_m,C_j} & \cdots & e_{O_m,C_l} & \cdots & e_{O_m,C_n} \end{array},$$

From the requirement for comparability above, it follows that for each $i$, $j$, $k$ it holds the relation $R(e_{O_iC_k}, e_{O_jC_k})$. The relation $R$ has dual relation $\overline{R}$, which is true in the cases when relation $R$ is false, and vice versa.

For the needs of our decision making method, pairwise comparisons between every two different criteria are made along all evaluated objects. During the comparison, it is maintained one counter of the number of times when the relation $R$ holds, and another counter for the dual relation.

Let $S^{\mu}_{k,l}$ be the number of cases in which the relations $R(e_{O_iC_k}, e_{O_jC_k})$ and $R(e_{O_iC_l}, e_{O_jC_l})$ are simultaneously satisfied. Let also $S^{\nu}_{k,l}$ be the number of cases in which the relations $R(e_{O_iC_k}, e_{O_jC_k})$ and its dual $\overline{R}(e_{O_iC_l}, e_{O_jC_l})$ are simultaneously satisfied. As the total number of pairwise comparisons between the object is $m(m-1)/2$, it is seen that there hold the inequalities:

$$0 \le S^{\mu}_{k,l} + S^{\nu}_{k,l} \le \frac{m(m-1)}{2}.$$

For every $k$, $l$, such that $1 \le k \le l \le m$, and for $m \ge 2$ two numbers are defined:

$$\mu_{C_k,C_l} = 2\frac{S^{\mu}_{k,l}}{m(m-1)},\quad \nu_{C_k,C_l} = 2\frac{S^{\nu}_{k,l}}{m(m-1)}.$$

The pair, constructed from these two numbers, plays the role of the intuitionistic fuzzy evaluation of the relations that can be established between any two criteria $C_k$ and $C_l$. In this way the index matrix $M$ that relates evaluated objects with evaluating criteria can be transformed to another index matrix $M^*$ that gives the relations among the criteria:

$$M^* = \begin{array}{c|ccc} & C_1 & \cdots & C_n \\ \hline C_1 & \langle \mu_{C_1,C_1}, \nu_{C_1,C_1}\rangle & \cdots & \langle \mu_{C_1,C_n}, \nu_{C_1,C_n}\rangle \\ \vdots & \vdots & \ddots & \vdots \\ C_n & \langle \mu_{C_n,C_1}, \nu_{C_n,C_1}\rangle & \cdots & \langle \mu_{C_n,C_n}, \nu_{C_n,C_n}\rangle \end{array}.$$

From practical considerations, it has been more flexible to work with two index matrices $M^{\mu}$ and $M^{\nu}$, rather than with the index matrix $M^{*}$ of IF pairs.

The final step of the algorithm is to determine the degrees of correlation between the criteria, depending on the user's choice of $\mu$ and $\nu$. We call these correlations between the criteria: 'positive consonance', 'negative consonance' or 'dissonance'. Let $\alpha$, $\beta \in [0; 1]$ be the threshold values, against which we compare the values of $\mu_{C_k,C_l}$ and $\nu_{C_k,C_l}$. We call that criteria $C_k$ and $C_l$ are in:

- $(\alpha, \beta)$-positive consonance, if $\mu_{C_k,C_l} > \alpha$ and $\nu_{C_k,C_l} < \beta$;
- $(\alpha,\beta)$-negative consonance, if $\mu_{C_k,C_l} < \beta$ and $\nu_{C_k,C_l} > \alpha$;
- $(\alpha, \beta)$-dissonance, otherwise.

The approach is completely data driven, and each new application would require taking specific threshold values $\alpha, \beta$ that will yield reliable results.

# 3 DATA PROCESSING

Here we dispose of and analyse the following input datasets from (Calogirou, et al., 2010):

- The number of enterprises in EU27, by country, divided to the four categories: Micro, Small, Medium and Large (p. 16, Table 4)
- The number of persons employed in EU27, by country, divided to the four categories: Micro, Small, Medium and Large (p. 18, Table 6)
- The Turnover (millions of €) in the EU27, by country, divided to the four categories: Micro, Small, Medium and Large (p. 20, Table 8)
- Value added at factor cost (millions of €), by country, divided to the four categories: Micro, Small, Medium and Large (p. 22, Table 10).

These four source datasets we rearrange in a way to discover for each of the four indicators: 'Number of enterprises (NE)', 'Number of persons employed (PE)', 'Turnover (TO)' and 'Value added at factor cost (VA)' what are the correlations between them in the different scale, given by the type of enterprises: 'Micro', 'Small', 'Medium' and 'Large'.

During this processing, we remove both the rows and the columns titled 'Total' and 'Pct', and remain to work only with the data countries by indicators, that are homogeneous in nature.

In these new 4 processed datasets (Tables 1–4), for each type of enterprise, we have one index matrix with 27 rows being the countries in the EU27, and 4 columns for the four indicators.

The data from Tables 1–4 concerning the micro, small, medium and large enterprises, have been analysed using a software application for InterCriteria Analysis, developed by one of the authors, Mavrov (Mavrov, 2014). The application follows the algorithm for ICA and produces from the matrix of 27 rows of countries (objects per rows) and 4 indicators (criteria per columns), two new matrices, containing respectively the membership and the non-membership parts of the IF pairs that form the IF positive, negative consonance and dissonance relations between each pair of criteria, In this case, the 4 criteria form 6 InterCriteria pairs.

Table 1: Data for the microenterprises in the EU27 countries, as evaluated against 4 criteria (in %).

| EU Member | NE | PE | TA | VO |
|---|---|---|---|---|
| **Austria** | 88 | 25 | 18 | 19 |
| **Belgium** | 92 | 30 | 21 | 19 |
| **Bulgaria** | 88 | 22 | 20 | 14 |
| **Cyprus** | 92 | 39 | 30 | 31 |
| **Czech Rep.** | 95 | 29 | 18 | 19 |
| **Denmark** | 87 | 19 | 23 | 28 |
| **Estonia** | 83 | 20 | 25 | 21 |
| **Finland** | 93 | 24 | 16 | 19 |
| **France** | 92 | 38 | 19 | 21 |
| **Germany** | 83 | 23 | 12 | 16 |
| **Greece** | 96 | 25 | 35 | 35 |
| **Hungary** | 94 | 58 | 21 | 18 |
| **Ireland** | 82 | 35 | 12 | 12 |
| **Italy** | 95 | 20 | 28 | 33 |
| **Latvia** | 83 | 47 | 23 | 19 |
| **Lithuania** | 88 | 23 | 13 | 12 |
| **Luxembourg** | 87 | 19 | 18 | 24 |
| **Malta** | 96 | 22 | 22 | 21 |
| **Netherlands** | 90 | 34 | 15 | 20 |
| **Poland** | 96 | 29 | 23 | 18 |
| **Portugal** | 95 | 39 | 26 | 24 |
| **Romania** | 88 | 42 | 16 | 14 |
| **Slovakia** | 76 | 21 | 13 | 13 |
| **Slovenia** | 93 | 25 | 20 | 20 |
| **Spain** | 92 | 28 | 23 | 27 |

| | | | | |
|---|---|---|---|---|
| **Sweden** | 94 | 15 | 18 | 20 |
| **United Kingdom** | 87 | 22 | 14 | 18 |

Table 2: Data for the small enterprises in the EU27 countries, as evaluated against 4 criteria (in %).

| EU Member | NE | PE | TA | VO |
|---|---|---|---|---|
| **Austria** | 11 | 23 | 23 | 20 |
| **Belgium** | 7 | 22 | 20 | 20 |
| **Bulgaria** | 9 | 24 | 21 | 18 |
| **Cyprus** | 7 | 25 | 29 | 26 |
| **Czech Rep.** | 4 | 19 | 18 | 16 |
| **Denmark** | 11 | 22 | 22 | 21 |
| **Estonia** | 14 | 25 | 29 | 25 |
| **Finland** | 6 | 28 | 14 | 16 |
| **France** | 6 | 26 | 19 | 19 |
| **Germany** | 14 | 19 | 16 | 18 |
| **Greece** | 3 | 21 | 23 | 20 |
| **Hungary** | 5 | 17 | 18 | 16 |
| **Ireland** | 15 | 19 | 20 | 17 |
| **Italy** | 5 | 26 | 23 | 23 |
| **Latvia** | 14 | 22 | 28 | 27 |
| **Lithuania** | 9 | 25 | 24 | 23 |
| **Luxembourg** | 11 | 24 | 24 | 20 |
| **Malta** | 4 | 28 | 22 | 20 |
| **Netherlands** | 8 | 20 | 21 | 21 |
| **Poland** | 3 | 21 | 13 | 12 |
| **Portugal** | 5 | 12 | 23 | 22 |
| **Romania** | 9 | 23 | 21 | 16 |
| **Slovakia** | 19 | 20 | 16 | 15 |
| **Slovenia** | 6 | 21 | 19 | 19 |
| **Spain** | 7 | 18 | 24 | 24 |
| **Sweden** | 5 | 18 | 18 | 18 |
| **United Kingdom** | 10 | 18 | 16 | 16 |

Table 3: Data for the medium enterprises in the EU27 countries, as evaluated against 4 criteria (in %).

| EU Member | NE | PE | TA | VO |
|---|---|---|---|---|
| **Austria** | 2 | 19 | 22 | 21 |
| **Belgium** | 1 | 16 | 19 | 19 |
| **Bulgaria** | 2 | 24 | 22 | 21 |
| **Cyprus** | 1 | 20 | 24 | 21 |
| **Czech Rep.** | 1 | 20 | 24 | 20 |
| **Denmark** | 2 | 19 | 22 | 19 |
| **Estonia** | 3 | 21 | 28 | 30 |
| **Finland** | 1 | 26 | 18 | 18 |
| **France** | 1 | 15 | 17 | 16 |
| **Germany** | 2 | 18 | 20 | 19 |
| **Greece** | 0 | 16 | 19 | 17 |
| **Hungary** | 1 | 12 | 19 | 18 |
| **Ireland** | 3 | 16 | 25 | 23 |
| **Italy** | 1 | 23 | 20 | 16 |
| **Latvia** | 3 | 12 | 28 | 28 |
| **Lithuania** | 2 | 26 | 27 | 29 |
| **Luxembourg** | 2 | 23 | 17 | 19 |
| **Malta** | 1 | 26 | 26 | 23 |
| **Netherlands** | 1 | 20 | 26 | 21 |
| **Poland** | 1 | 17 | 23 | 22 |
| **Portugal** | 1 | 19 | 22 | 21 |
| **Romania** | 2 | 16 | 21 | 20 |
| **Slovakia** | 4 | 23 | 21 | 18 |
| **Slovenia** | 1 | 18 | 24 | 21 |
| **Spain** | 1 | 21 | 20 | 17 |
| **Sweden** | 1 | 23 | 19 | 18 |
| **United Kingdom** | 2 | 15 | 18 | 17 |

Table 4: Data for the large enterprises in the EU27 countries, as evaluated against 4 criteria (in %).

| EU Member | NE | PE | TA | VO |
|---|---|---|---|---|
| **Austria** | 0.3 | 33 | 37 | 40 |
| **Belgium** | 0.2 | 33 | 39 | 42 |
| **Bulgaria** | 0.3 | 30 | 37 | 46 |
| **Cyprus** | 0.2 | 17 | 17 | 21 |
| **Czech Rep.** | 0.2 | 32 | 41 | 45 |
| **Denmark** | 0.3 | 40 | 33 | 32 |

| | | | | |
|---|---|---|---|---|
| **Estonia** | 0.4 | 34 | 18 | 24 |
| **Finland** | 0.3 | 22 | 52 | 46 |
| **France** | 0.2 | 22 | 44 | 45 |
| **Germany** | 0.5 | 41 | 52 | 47 |
| **Greece** | 0.1 | 38 | 23 | 28 |
| **Hungary** | 0.2 | 13 | 41 | 48 |
| **Ireland** | 0.5 | 29 | 43 | 48 |
| **Italy** | 0.1 | 32 | 29 | 28 |
| **Latvia** | 0.3 | 19 | 20 | 26 |
| **Lithuania** | 0.3 | 25 | 35 | 36 |
| **Luxembourg** | 0.4 | 33 | 42 | 37 |
| **Malta** | 0.1 | 24 | 30 | 36 |
| **Netherlands** | 0.3 | 26 | 38 | 38 |
| **Poland** | 0.2 | 33 | 41 | 48 |
| **Portugal** | 0.1 | 31 | 30 | 32 |
| **Romania** | 0.4 | 18 | 41 | 50 |
| **Slovakia** | 1.0 | 36 | 50 | 54 |
| **Slovenia** | 0.3 | 36 | 37 | 40 |
| **Spain** | 0.1 | 33 | 33 | 32 |
| **Sweden** | 0.2 | 44 | 44 | 44 |
| **United Kingdom** | 0.4 | 45 | 51 | 49 |

Because of the diverse nature of the types of enterprises (micro, small, medium or large enterprises), it is expected that these six InterCriteria pairs will be different depending on which kind of enterprises are taken into consideration.

Thus, for the micro enterprises, for which are the data in Table 1, the two index matrices with InterCriteria pairs are respectively given in Table 5, for the small enterprises the two index matrices are given in Table 2 – in Table 6, for the medium enterprises, for which are the data in Table 3, the two index matrices are given in Table 7, and for the large enterprises for which are the data are in Table 4, the two index matrices are given in Table 8.

Respectively, the InterCriteria correlation pairs for small, medium and large enterprises are given in Tables 5–8. We can immediately note the similar patterns in the conditional formatting of the eight tables in Tables 5–8, which are highlighted in a way to outline the highest possible positive consonances.

Table 5: InterCriteria pairs in micro enterprises.

| $\mu$ | NE | PE | TO | VA |
|---|---|---|---|---|
| **NE** | 1.000 | 0.504 | 0.621 | 0.584 |
| **PE** | 0.504 | 1.000 | 0.496 | 0.413 |
| **TO** | 0.621 | 0.496 | 1.000 | 0.735 |
| **VA** | 0.584 | 0.413 | 0.735 | 1.000 |

| $\nu$ | NE | PE | TO | VA |
|---|---|---|---|---|
| **NE** | 0.000 | 0.396 | 0.256 | 0.285 |
| **PE** | 0.396 | 0.000 | 0.425 | 0.493 |
| **TO** | 0.256 | 0.425 | 0.000 | 0.160 |
| **VA** | 0.285 | 0.493 | 0.160 | 0.000 |

Table 6: InterCriteria pairs in small enterprises.

| $\mu$ | NE | PE | TO | VA |
|---|---|---|---|---|
| **NE** | 1.000 | 0.436 | 0.533 | 0.484 |
| **PE** | 0.436 | 1.000 | 0.567 | 0.527 |
| **TO** | 0.533 | 0.567 | 1.000 | 0.803 |
| **VA** | 0.484 | 0.527 | 0.803 | 1.000 |

| $\nu$ | NE | PE | TO | VA |
|---|---|---|---|---|
| **NE** | 0.000 | 0.447 | 0.362 | 0.387 |
| **PE** | 0.447 | 0.000 | 0.319 | 0.342 |
| **TO** | 0.362 | 0.319 | 0.000 | 0.077 |
| **VA** | 0.387 | 0.342 | 0.077 | 0.000 |

Table 7: InterCriteria pairs in medium enterprises.

| $\mu$ | NE | PE | TO | VA |
|---|---|---|---|---|
| **NE** | 1.000 | 0.316 | 0.433 | 0.456 |
| **PE** | 0.316 | 1.000 | 0.516 | 0.467 |
| **TO** | 0.433 | 0.516 | 1.000 | 0.781 |
| **VA** | 0.456 | 0.467 | 0.781 | 1.000 |

| $\nu$ | NE | PE | TO | VA |
|---|---|---|---|---|
| **NE** | 0.000 | 0.299 | 0.222 | 0.182 |
| **PE** | 0.299 | 0.000 | 0.376 | 0.385 |
| **TO** | 0.222 | 0.376 | 0.000 | 0.088 |
| **VA** | 0.182 | 0.385 | 0.088 | 0.000 |

Table 8: InterCriteria pairs in large enterprises.

| $\mu$ | NE | PE | TO | VA |
|---|---|---|---|---|
| **NE** | 1.000 | 0.453 | 0.578 | 0.567 |
| **PE** | 0.453 | 1.000 | 0.527 | 0.481 |
| **TO** | 0.578 | 0.527 | 1.000 | 0.829 |
| **VA** | 0.567 | 0.481 | 0.829 | 1.000 |

| $\nu$ | NE | PE | TO | VA |
|---|---|---|---|---|
| **NE** | 0.000 | 0.328 | 0.242 | 0.248 |
| **PE** | 0.328 | 0.000 | 0.399 | 0.450 |
| **TO** | 0.242 | 0.399 | 0.000 | 0.120 |
| **VA** | 0.248 | 0.450 | 0.120 | 0.000 |

## 4 RESULTS AND DISCUSSION

Following a recent idea about analysis of the results of application of the ICA approach, described in (Atanassova, 2015), we can interpret the IF pairs, representing the membership and the non-membership parts of the InterCriteria correlation, as coordinates of points in the IF interpretation triangle, (Atanassov, 1989).

We will note for the interested reader, that the intuitionistic fuzzy interpretation triangle, see Figure 1, is the IFS-specific graphical interpretation of IFSs, which is not available for graphical interpretation of the ordinary fuzzy sets, defined by Zadeh. The triangle is part of the Euclidean plane, with vertices the points (0, 0), (1, 0) and (0, 1), staying respectively for the complete uncertainty, complete truth and complete falsity as the boundary values with which elements of an IFS can be evaluated. The hypotenuse corresponds to the graphical interpretation of the [0, 1]-interval, and points belonging to it are elements of a classical fuzzy set.

In this interpretation, we can plot the 24 resultant points onto a single IF triangle: 6 InterCriteria correlation points for the 4 types of enterprises. Since we are interested in the highest InterCriteria correlations, in these terms, it means finding the points, which are closest to the complete truth in point (1, 0), which is equivalent to having their membership parts greater than a given threshold value $\alpha$, and, simultaneously, their non-membership parts less than a second threshold value $\beta$. For each of the points, i.e. for each of the correlations between two different criteria $C_i$ and $C_j$, $i \neq j$, we can calculate its distance from the (1, 0) point, according to the simple formula:

$$d_{C_i,C_j} = \sqrt{(1-\mu_{C_iC_j})^2 + \nu_{C_iC_j}{}^2}$$

The results are given in Table 9, and presented sorted in ascending order according to the distance.

Table 9: Ranking the InterCriteria pairs by distance to Truth (1, 0).

| Enterprise type | $C_i$ | $C_j$ | $\mu_{CiCj}$ | $\nu_{CiCj}$ | $d_{CiCj}$ |
|---|---|---|---|---|---|
| **Large** | TO | VA | 0.829 | 0.120 | 0.209 |
| **Small** | TO | VA | 0.803 | 0.077 | 0.212 |
| **Medium** | TO | VA | 0.781 | 0.088 | 0.236 |
| **Micro** | TO | VA | 0.735 | 0.160 | 0.310 |
| **Micro** | NE | TO | 0.621 | 0.256 | 0.457 |
| **Large** | NE | TO | 0.578 | 0.242 | 0.486 |
| **Large** | NE | VA | 0.567 | 0.248 | 0.499 |
| **Micro** | NE | VA | 0.584 | 0.285 | 0.504 |
| **Small** | PE | TO | 0.567 | 0.319 | 0.538 |
| **Medium** | NE | VA | 0.456 | 0.182 | 0.574 |
| **Small** | PE | VA | 0.527 | 0.342 | 0.584 |
| **Small** | NE | TO | 0.533 | 0.362 | 0.591 |
| **Medium** | NE | TO | 0.433 | 0.222 | 0.609 |
| **Medium** | PE | TO | 0.516 | 0.376 | 0.613 |
| **Large** | PE | TO | 0.527 | 0.399 | 0.619 |
| **Micro** | NE | PE | 0.504 | 0.396 | 0.635 |
| **Large** | NE | PE | 0.453 | 0.328 | 0.638 |
| **Small** | NE | VA | 0.484 | 0.387 | 0.645 |
| **Medium** | PE | VA | 0.467 | 0.385 | 0.658 |
| **Micro** | PE | TO | 0.496 | 0.425 | 0.659 |
| **Large** | PE | VA | 0.481 | 0.450 | 0.687 |
| **Small** | NE | PE | 0.436 | 0.447 | 0.720 |
| **Medium** | NE | PE | 0.316 | 0.299 | 0.746 |
| **Micro** | PE | VA | 0.413 | 0.493 | 0.767 |

We can, then, make two rounds of discussions. On one hand, see Figure 1, we can seek and formulate some assumptions about the InterCriteria correlations with respect to the type of enterprise.

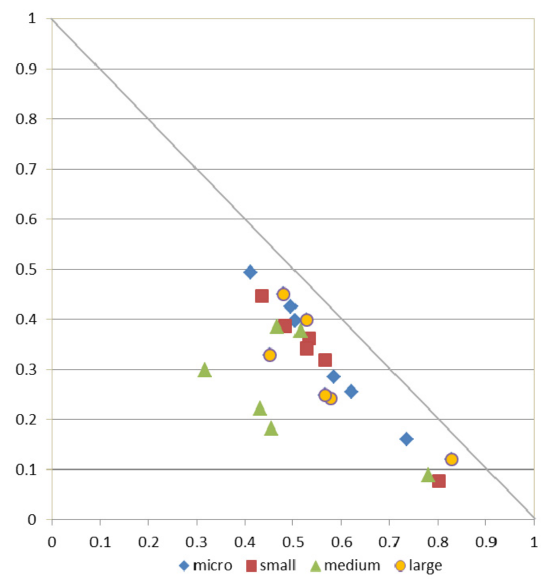


Figure 1: ICA results with respect to the type of enterprise.

We can notice from here that micro and small enterprises exhibit very similar patterns of InterCriteria consonance, with all the InterCriteria pairs exhibiting relatively low levels of uncertainty, and only the pair TO/VA exhibiting relatively high positive consonances. The same pair ranges highest among the InterCriteria correlations with the other two types of enterprises, medium and large. The large type of enterprises also exhibits relatively low uncertainty in the InterCriteria correlations, being lowest with TO/VA, PE/TO and PE/VA, and highest uncertainty featured in the rest three of the pairs. Expectedly, the most scattered is the pattern with the medium type of enterprises, where also the largest uncertainty is observed, all in the pairs containing the number of enterprises: NE/PE, NE/TO and NE/VA.

On the other hand, it is considered appropriate to analyse these 24 points as 6 groups of 4 points, grouped according to the criteria in the pair (Figure 2). We can then make some assumptions about the nature of these correlations, judging from how concentrated or how scattered the four points in each group are: the more concentrated the points for a given InterCriteria pair, the more consistent behaviour of this pair across the different scales of economic entities.

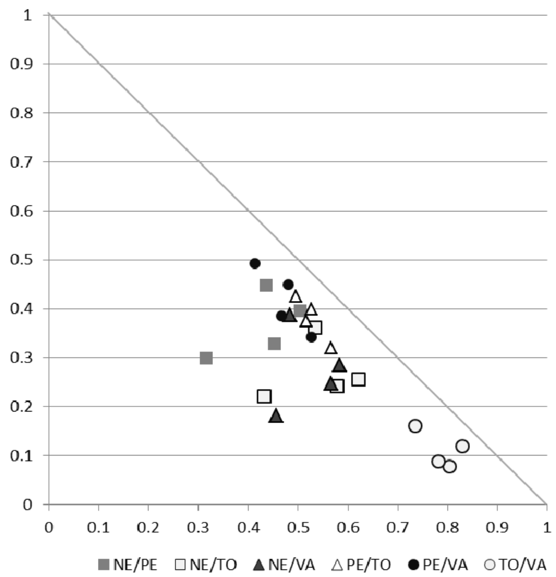


Figure 2: ICA results with respect to correlations between economic indicators.

We will immediately note what was visible from the Table 9, that that the pair of criteria TO/VA are distinctly best correlating across the different scales of economic entities, concentrated in the closest proximity to the absolute truth represented by the (1, 0) point. It is interesting however to note other, less clearly seen relations. For instance, we can note that quite similar patterns are formed for the two four-point sets corresponding to the pairs of criteria PE/VA and PE/TO: relatively parallel and closely located to the hypothenuse. In both these pairs, the distances from the (1, 0) point, according to the type of enterprise, follow in decreasing order the sequence: 'small' – 'medium' – 'large' – 'micro', with medium and large enterprises exhibiting very close results. Quite similar and closely located to each other are also the patterns for the pairs of criteria NE/TO and NE/VA.

These three observations over these particular economic data lead us to the speculation that from theoretical point of view it would be interesting to pay attention to situations when we have two criteria $C_i$, $C_j$ that exhibit high positive consonance with each other, and each of them exhibit similar or identical consonance patterns in the pairs $C_i$–$C_k$ and $C_j$–$C_k$, or vice versa, if $C_i$–$C_k$ and $C_j$–$C_k$ are two pairs of criteria with high positive consonances, would there be high positive consonance in the pair $C_i$–$C_j$. This question would be worth exploring in the light of the possibility to detect, using ICA not just pairs of correlating criteria, but also triplets, etc.

## 5 CONCLUSION

The present research analysed data about the micro, small, medium and large economic entities in the EU27, as evaluated against four economic indicators (criteria). The utilised method for analysis of the datasets was the novel decision support approach, called InterCriteria Analysis. The results are two-fold: they outline correlations between economic indicators on these four levels of economic enterprise, new thus potentially brining new knowledge and understanding, and also contribute to elaboration of certain aspects of the methodology of ICA.

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# InterCriteria Decision Making Approach for Iron Powder Briquetting

Lyubka Doukovska[1], Dimitar Karastoyanov[1], Nikolay Stoymenov[1] and Ivan Kalaykov[2]

[1] *Institute of Information and Communication Technologies, Bulgarian Academy of Sciences*
*Acad. G. Bonchev str., bl. 2, 1113 Sofia, Bulgaria*
*doukovska@iit.bas.bg, dkarast@iinf.bas.bg, nikistoimenow@gmail.com*

[2] *Örebro University, School of Science and Technology*
*SE-701 82 Örebro, Sweden*
*ivan.kalaykov@oru.se*

Keywords: InterCriteria decision making, Index matrix, Impact briquetting.

Abstract: In this paper, we present approach, called 'InterCriteria Decision Making' that utilizes the apparatus of index matrices and intuitionistic fuzzy sets which from an existing multiobject multicriteria evaluation table generates a new table that contains estimations of the pairwise relations among the set of evaluating criteria. In the presented paper for the analysis purposes we have used experimental results of impact briquetting of iron powder. In this study we illustrate the application of the one original methodology to the data achieved for the following parameters - distance, speed and acceleration of the impacting bodies. The research and the obtained results will show relations between the briquetting process parameters which will lead to increase in its efficiency.

## 1 INTRODUCTION

Producing briquettes using metal chips and powder is an actual scientific problem which is reflected in a lot off publications. This technology recently is being applied more widely as per (Penchev, 2014; Radeva et al., 2014; Gustavson at al., 2014; Doremus at al., 2010; Scoglund, 2001). The positive results related to the density increasing with the impact power increases are a reason for investigating the effect using iron powder. In paper (Gustavson at al., 2014) it is shown that when compacting iron powder with impact speed 15 [m/s] a cylindrical sample of size height $H$ = 20 [mm], diameter $D$ = 25 [mm] and density $\rho$ = 7.4 [gr/cm$^3$] has been produced. At the same time the monolith material has a density $\rho$ = 7.5 [gr/cm$^3$]. This is mainly influenced by the high impact energy determined by the higher speed.

In this study we illustrate the application of the one original methodology to the data achieved for the following parameters - distance, speed and acceleration of the impacting bodies. These are analyzed by means of high speed camera and the applicable software. The impact energy ($E_y$) and power ($F_y$) are calculated. To get more experimental data an Xray tomograph Nikon XTH 225 Compact Industrial CT Scanner has been used. They are part of the equipment of the Smart Lab at IICT.

In process of the metal chips briquetting, mechanical and hydraulic presses with nominal force of several hundred to several thousand kN are used. The goal is to obtain briquettes with good density - the ratio $H/D$ for different materials vary within wide limits ($H/D$ = 0.8 – 0.25), where H is the height, and $D$ is the diameter of the briquette. The greater is the density of the briquettes, the smaller are the losses in the transport and melting. Basic data used to evaluate the effect of briquetting operation is the specific density of the briquette ($\rho$, [g/cm$^3$]), and specific contact pressure for briquetting ($P$, [MPa]).

In the presented paper we have analyzed experimental results of iron powder briquetting. The experiments are conducted using a complicated (combined) impacting device, shown on Figure 1.

Main element of this device is a cold rocket engine 12, working on pressurized air with pressure up to 33 [MPa]. The usage of such an engine allows for a combined impact with power $F_y$ and additional power $R$.

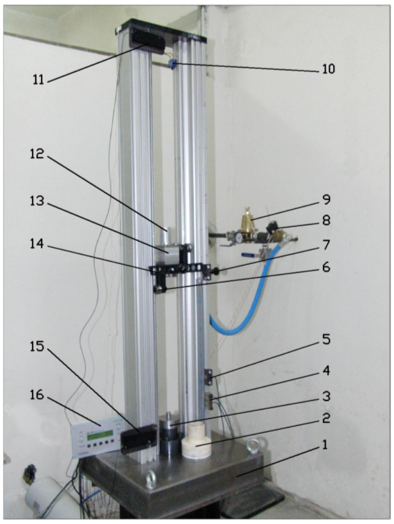



Figure 1: Laboratory stend for a complicated impact investigation:
1 – main plate weight of 220 [kg]; 2 – plastic element for elastic impact investigation; 3 – plastic impact sensor; 4 – inductive speed sensors; 5 – lower position inductive air on/off sensor; 6 – falling part rails; 7 – trigger; 8 – solenoid valve; 9 – air pressure controller; 10 – upper position inductive air on/off sensor; 11, 15 – light sensor and source for the falling part speed measurement; 12 – cold rocket engine; 13 – falling part with weight of 6.17 [kg]; 14 – plate for sensors 4, 5, 11; 16 – control panel.

To conduct the iron powder briquetting experiments we use the same stand and equipment as we did for the iron chips. The size of the particles of the iron powder we used (brand AS29-100) is determined using Fritch Analysette 22 Nano Tec+.

After high speed filming of the impact the material is processed using Vicasso 2009 product and as a result we have diagrams of the distance, speed and acceleration. Based on that we determine the impact speed $V_y$ and acceleration $A_y$. Then the impact energy and power are being calculated using this data.

# 2 INTERCRITERIA DECISION MAKING APPROACH

The presented multicriteria decision making method is based on two fundamental concepts: intuitionistic fuzzy sets and index matrices. It is called 'InterCriteria decision making'.

Intuitionistic fuzzy sets defined by Atanassov (Atanassov, 1983; Atanassov, 1986; Atanassov, 1999; Atanassov, 2012) represent an extension of the concept of fuzzy sets, as defined by Zadeh (Zadeh, 1965), exhibiting function $\mu_A(x)$ defining the membership of an element $x$ to the set $A$, evaluated in the [0; 1] - interval. The difference between fuzzy sets and intuitionistic fuzzy sets (IFSs) is in the presence of a second function $\nu_A(x)$ defining the non-membership of the element $x$ to the set $A$, where:

$$0 \le \mu_A(x) \le 1,$$

$$0 \le \nu_A(x) \le 1,$$

$$0 \le \mu_A(x) + \nu_A(x) \le 1.$$

The IFS itself is formally denoted by:

$$A = \{\langle x, \mu_A(x), \nu_A(x)\rangle \mid x \in E\}.$$

Comparison between elements of any two IFSs, say $A$ and $B$, involves pairwise comparisons between their respective elements' degrees of membership and non-membership to both sets.

The second concept on which the proposed method relies is the concept of index matrix, a matrix which features two index sets. The theory behind the index matrices is described in (Atanassov, 1991). Here we will start with the index matrix $M$ with index sets with $m$ rows $\{C_1,\ldots,C_m\}$ and $n$ columns $\{O_1,\ldots,O_n\}$:

$$M = \begin{array}{c|ccccccc} & O_1 & \ldots & O_k & \ldots & O_l & \ldots & O_n \\ \hline C_1 & a_{C_1,O_1} & \ldots & a_{C_1,O_k} & \ldots & a_{C_1,O_l} & \ldots & a_{C_1,O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_i & a_{C_i,O_1} & \ldots & a_{C_i,O_k} & \ldots & a_{C_i,O_l} & \ldots & a_{C_i,O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_j & a_{C_j,O_1} & \ldots & a_{C_j,O_k} & \ldots & a_{C_j,O_l} & \ldots & a_{C_j,O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_m & a_{C_m,O_1} & \ldots & a_{C_m,O_j} & \ldots & a_{C_m,O_l} & \ldots & a_{C_m,O_n} \end{array},$$

where for every $p$, $q$ ($1 \le p \le m$, $1 \le q \le n$), $C_p$ is a criterion (in our case, one of the twelve pillars), $O_q$ in an evaluated object, $a_{C_pO_q}$ is the evaluation of the $q$-th object against the $p$-th criterion, and it is defined as a real number or another object that is comparable according to relation $R$ with all the rest elements of the index matrix $M$, so that for each $i$, $j$, $k$ it holds the relation $R(a_{C_kO_i}, a_{C_kO_j})$. The relation $R$ has dual relation $\overline{R}$, which is true in the cases when relation $R$ is false, and vice versa.

For the needs of our decision making method, pairwise comparisons between every two different criteria are made along all evaluated objects. During the comparison, it is maintained one counter of the number of times when the relation $R$ holds, and another counter for the dual relation.

Let $S^{\mu}_{k,l}$ be the number of cases in which the relations $R(a_{C_k O_i}, a_{C_k O_j})$ and $R(a_{C_l O_i}, a_{C_l O_j})$ are simultaneously satisfied. Let also $S^{\nu}_{k,l}$ be the number of cases in which the relations $R(a_{C_k O_i}, a_{C_k O_j})$ and its dual $\overline{R}(a_{C_l O_i}, a_{C_l O_j})$ are simultaneously satisfied. As the total number of pairwise comparisons between the object is $n(n-1)/2$, it is seen that there hold the inequalities:

$$0 \le S^{\mu}_{k,l} + S^{\nu}_{k,l} \le \frac{n(n-1)}{2}.$$

For every $k$, $l$, such that $1 \le k \le l \le m$, and for $n \ge 2$ two numbers are defined:

$$\mu_{C_k,C_l} = 2\frac{S^{\mu}_{k,l}}{n(n-1)}, \quad \nu_{C_k,C_l} = 2\frac{S^{\nu}_{k,l}}{n(n-1)}.$$

The pair constructed from these two numbers plays the role of the intuitionistic fuzzy evaluation of the relations that can be established between any two criteria $C_k$ and $C_l$. In this way the index matrix $M$ that relates evaluated objects with evaluating criteria can be transformed to another index matrix $M^*$ that gives the relations among the criteria:

$$M^* = \begin{array}{c|ccc} & C_1 & \cdots & C_m \\ \hline C_1 & \langle \mu_{C_1,C_1}, \nu_{C_1,C_1} \rangle & \cdots & \langle \mu_{C_1,C_m}, \nu_{C_1,C_m} \rangle \\ \vdots & \vdots & \ddots & \vdots \\ C_m & \langle \mu_{C_m,C_1}, \nu_{C_1,C_m} \rangle & \cdots & \langle \mu_{C_m,C_m}, \nu_{C_m,C_m} \rangle \end{array}.$$

The final step of the algorithm is to determine the degrees of correlation between the criteria, depending on the user's choice of $\mu$ and $\nu$. We call these correlations between the criteria: 'positive consonance', 'negative consonance' or 'dissonance'.

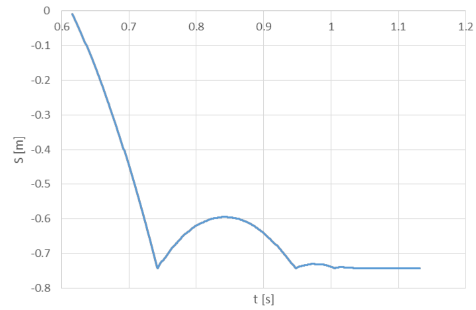
Let $\alpha, \beta \in [0; 1]$ be given, so that $\alpha + \beta \le 1$. We call that criteria $C_k$ and $C_l$ are in:

- $(\alpha, \beta)$ - positive consonance, if $\mu_{C_k, C_l} > \alpha$ and $\nu_{C_k,C_l} < \beta$;
- $(\alpha, \beta)$ - negative consonance, if $\mu_{C_k,C_l} < \beta$ and $\nu_{C_k,C_l} > \alpha$;
- $(\alpha, \beta)$ - dissonance, otherwise.

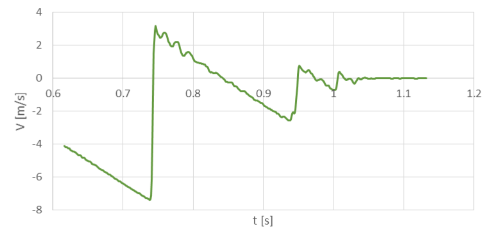
Obviously, the larger $\alpha$ and/or the smaller $\beta$, the less number of criteria may be simultaneously connected with the relation of $(\alpha, \beta)$ - positive consonance. For practical purposes, it carries the most information when either the positive or the negative consonance is as large as possible, while the cases of dissonance are less informative and can be skipped.

## 3 EXPERIMENTAL RESULTS

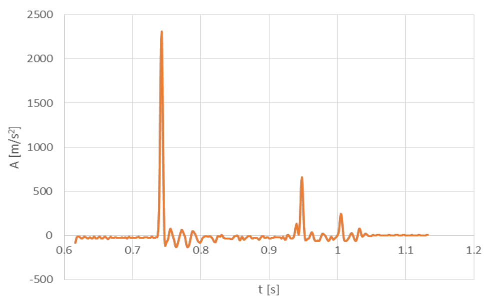
In the presented paper for the analysis purposes we have used experimental results of impact briquetting of iron powder. Figure 2 shows the distance, speed and acceleration diagrams when briquetting iron powder.




a)




b)




c)

Figure 2: Distance (a), speed (b) and acceleration (c) diagrams when briquetting iron powder.

Figure 2 shows also that the acceleration and hence the force when briquetting iron powder is 38.4% higher compared to the corresponding values when briquetting iron chips.

Our experiments show that in order to improve the capabilities of this deformation process, additional investigations are required. We also prove that to have a better density in detail's walls, where we have big tension powers, a lubricant has to be added.

The analysis shows that for specific energy $E_c$=488 [J/cm$^3$] and impact speed $V_y$=7.37 [m/s] a cylindrical compacted iron powder sample has been produced, having density of $\rho$=6.7582 [gr/cm$^3$]. These impact process parameters can be assumed the best ones achieved for rocket engine thrust of $R$=226 [kN].

Based on the experimental research the values of eleven parameters of the iron powder briquetting process have been obtained:

1 - $V_y$ – Impact speed, [m/s];
2 - $A_y$ – Impact acceleration, [m/s$^2$];
3 - $H_\Delta$ – Trimming height, [mm];
4 - $H$ – Briquette height, [cm];
5 - $D$ – Briquette diameter, [cm];
6 - $V$ – Briquette volume, [cm$^3$];
7 - $G$ – Briquette weight, [gr];
8 - $\rho$ – Briquette density, [gr/cm$^3$];
9 - $E_y$ – Impact energy, [J];
10 - $E_c$ – Impact specific energy, [J/cm$^3$];
11 - $F_y$ – Power of impact, [N].

Table 1: Membership pairs of the intuitionistic fuzzy InterCriteria correlations for the iron powder briquette.

| μ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.000 | 0.528 | 0.389 | 0.417 | 0.333 | 0.417 | 0.611 | 0.611 | 1.000 | 0.611 | 0.528 |
| 2 | 0.528 | 1.000 | 0.694 | 0.167 | 0.250 | 0.167 | 0.306 | 0.639 | 0.528 | 0.861 | 1.000 |
| 3 | 0.389 | 0.694 | 1.000 | 0.361 | 0.278 | 0.361 | 0.167 | 0.333 | 0.389 | 0.611 | 0.694 |
| 4 | 0.417 | 0.167 | 0.361 | 1.000 | 0.722 | 1.000 | 0.694 | 0.306 | 0.417 | 0.028 | 0.167 |
| 5 | 0.333 | 0.250 | 0.278 | 0.722 | 1.000 | 0.722 | 0.722 | 0.500 | 0.333 | 0.278 | 0.250 |
| 6 | 0.417 | 0.167 | 0.361 | 1.000 | 0.722 | 1.000 | 0.694 | 0.306 | 0.417 | 0.028 | 0.167 |
| 7 | 0.611 | 0.306 | 0.167 | 0.694 | 0.722 | 0.694 | 1.000 | 0.611 | 0.611 | 0.333 | 0.306 |
| 8 | 0.611 | 0.639 | 0.333 | 0.306 | 0.500 | 0.306 | 0.611 | 1.000 | 0.611 | 0.722 | 0.639 |
| 9 | 1.000 | 0.528 | 0.389 | 0.417 | 0.333 | 0.417 | 0.611 | 0.611 | 1.000 | 0.611 | 0.528 |
| 10 | 0.611 | 0.861 | 0.611 | 0.028 | 0.278 | 0.028 | 0.333 | 0.722 | 0.611 | 1.000 | 0.861 |
| 11 | 0.528 | 1.000 | 0.694 | 0.167 | 0.250 | 0.167 | 0.306 | 0.639 | 0.528 | 0.861 | 1.000 |

These have been analysed applying InterCriteria decision making approach. The results are presented in Table 1.

The results show a strong relation between the parameter pairs: 1 ('Impact speed') – 9 ('Impact energy'); 2 ('Impact acceleration') – 11 ('Power of impact'); 4 ('Briquette height') – 6 ('Briquette volume'); 2 ('Impact acceleration') – 10 ('Impact specific energy'); 10 ('Impact specific energy') – 11 ('Power of impact'); 5 ('Briquette diameter') – 6 ('Briquette volume'); 5 ('Briquette diameter') – 7 ('Briquette weight').

Part of these relations is due to the specific physical properties of the briquettes, which confirms the reliability of the proposed InterCriteria decision making approach. The benefit here is that this allows for finding strong dependencies as well as such where the relations are not so visible.

The graphical interpretation results with the intuitionistic fuzzy pairs of InterCriteria consonances is shown on Figure 3.

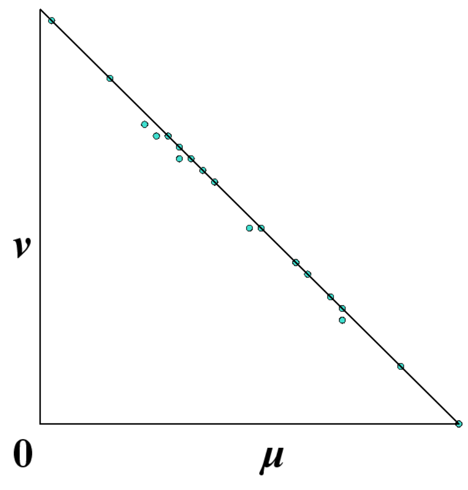



Figure 3: Geometrical visualisation of the InterCriteria correlations for the case of iron powder briquette onto the intuitionistic fuzzy interpretational triangle.

# 4 CONCLUSION

The research conducted shows that when producing rectangular form briquettes presence of air is observed in the final product. This is due to not absolutely complete filling of the peripheral part of the briquette. As a result the briquettes are of low density and decreased quality. To increase the product quality it is proposed elements with smaller size to be used. A possible solution is using iron powder.

The present paper proves the application of this original InterCriteria decision making approach, which eases the analysis if the relations between the criteria, giving better production quality.

# ACKNOWLEDGEMENTS

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# InterCriteria Decision Making Approach for Metal Chips Briquetting

Dimitar Karastoyanov[1], Lyubka Doukovska[1], Stanislav Gyoshev[1] and Ivan Kalaykov[2]

[1] Institute of Information and Communication Technologies, Bulgarian Academy of Sciences
Acad. G. Bonchev str., bl. 2, 1113 Sofia, Bulgaria
doukovska@iit.bas.bg, dkarast@iinf.bas.bg, stanislavgyoshev@mail.bg

[2] Örebro University, School of Science and Technology
SE-701 82 Örebro, Sweden
ivan.kalaykov@oru.se

Keywords: InterCriteria decision making, Index matrix, Impact briquetting.

Abstract: In the presented paper for the analysis purposes we have used experimental results of impact briquetting of grey cast iron chips. The presented multicriteria decision making method is based on two fundamental concepts: intuitionistic fuzzy sets and index matrices. We have named it 'InterCriteria' decision making approach, which utilizes the apparatus of index matrices and intuitionistic fuzzy sets - takes an existing multiobject multicriteria evaluation table and generates a new table that contains estimations of the pairwise relations among the set of evaluating criteria. Our goal is to increase the efficiency of the process of briquetting metal chips with good density and quality.

## 1 INTRODUCTION

Producing briquettes using metal chips and powder is an actual scientific problem which is reflected in a lot off publications. In paper (Bodurov et al., 2005) is proposed an original construction of die forging hammer propelled by industrial rocket engine. With this machine it is possible to work with controlled impact and with impact velocities from 4.5 [m/s] up to 20 [m/s]. Laboratory set-up for controlled impact, and the results of experimental study of metal chips briquetting by controlled impact with impact speed of 7 [m/s] are presented in paper (Gustavson et al, 2014). The potentiality to produce parts using such briquettes is also illustrated.

The technological effects of a controlled impact application in plastic deformation and briquetting of metal chips processes are discussed in (Penchev et al., 2013; Penchev et al., 2014; Penchev et al., 2014; Radeva et al., 2014). It was found that using a controlled impact increases the deformation up to 27% and the density of the briquettes up to 20% when compared to the ordinary impact. In (Penchev et al., 2014) is investigated the possibility of processing briquettes via plastic deformation of aluminum alloy chips (the density of the briquettes in this case is 93% of the density of the solid alloy). It was found that this is possible if stresses in the deformed body are compressive. In the presented paper for the analysis purposes we have used experimental results of impact briquetting of grey cast iron chips. In this study the parameters distance, speed, acceleration of the impacting bodies are analysed by means of high speed camera and the applicable software. They are part of the equipment of the Smart Lab at IICT.

The impact energy ($E_y$) and power ($F_y$) are calculated. To get more experimental data an Xray tomograph Nikon XTH 225 Compact Industrial CT Scanner has been used. This way the horizontal and vertical briquette sections have been investigated. The resolution of the obtained images is 5 [µm]. Based on these, we automatically determine the briquette diameter ($D$ [mm]) and its height ($H$ [mm]), with 4$^{th}$ decimal symbol accuracy.

In process of the metal chips briquetting, mechanical and hydraulic presses with nominal force of several hundred to several thousand kN are used. The goal is to obtain briquettes with good density - the ratio $H/D$ for different materials vary within wide limits ($H/D$ = 0.8 – 0.25), where H is the height, and $D$ is the diameter of the briquette. The greater is the density of the briquettes, the smaller are the losses in the transport and melting. Basic data used to evaluate the effect of briquetting operation is the specific density of the briquette ($\rho$, [g/cm$^3$]), and specific contact pressure for briquetting ($P$, [MPa]).

Figure 1 shows the laboratory stand with a high speed camera and special lighting, for taking high-speed video recordings. Using the camera and software makes possible to determine the speed $V_y$ and acceleration $A_y$ and then to calculate the impact energy $E_y$ and the power of impact $F_y$.

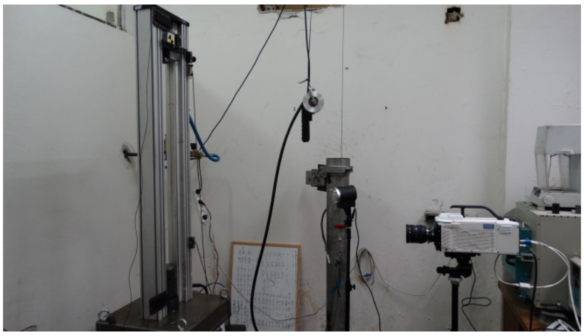

Figure 1: Laboratory stend for a complicated impact with high speed camera.

## 2 INTERCRITERIA DECISION MAKING APPROACH

The presented multicriteria decision making method is based on two fundamental concepts: intuitionistic fuzzy sets and index matrices. It is called 'InterCriteria decision making'.

Intuitionistic fuzzy sets defined by Atanassov (Atanassov, 1983; Atanassov, 1986; Atanassov, 1999; Atanassov, 2012) represent an extension of the concept of fuzzy sets, as defined by Zadeh (Zadeh, 1965), exhibiting function $\mu_A(x)$ defining the membership of an element $x$ to the set $A$, evaluated in the [0; 1] - interval. The difference between fuzzy sets and intuitionistic fuzzy sets (IFSs) is in the presence of a second function $\nu_A(x)$ defining the non-membership of the element $x$ to the set $A$, where:

$$0 \le \mu_A(x) \le 1,$$

$$0 \le \nu_A(x) \le 1,$$

$$0 \le \mu_A(x) + \nu_A(x) \le 1.$$

The IFS itself is formally denoted by:

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\hline
C_1 & a_{C_1,O_1} & \ldots & a_{C_1,O_k} & \ldots & a_{C_1,O_l} & \ldots & a_{C_1,O_n} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
C_i & a_{C_i,O_1} & \ldots & a_{C_i,O_k} & \ldots & a_{C_i,O_l} & \ldots & a_{C_i,O_n} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
C_j & a_{C_j,O_1} & \ldots & a_{C_j,O_k} & \ldots & a_{C_j,O_l} & \ldots & a_{C_j,O_n} \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\
C_m & a_{C_m,O_1} & \ldots & a_{C_m,O_j} & \ldots & a_{C_m,O_l} & \ldots & a_{C_m,O_n}
\end{array},$$

where for every $p$, $q$ ($1 \le p \le m$, $1 \le q \le n$), $C_p$ is a criterion (in our case, one of the twelve pillars), $O_q$ in an evaluated object, $a_{C_pO_q}$ is the evaluation of the $q$-th object against the $p$-th criterion, and it is defined as a real number or another object that is comparable according to relation $R$ with all the rest elements of the index matrix $M$, so that for each $i$, $j$, $k$ it holds the relation $R(a_{C_kO_i}, a_{C_kO_j})$. The relation $R$ has dual relation $\overline{R}$, which is true in the cases when relation $R$ is false, and vice versa.

For the needs of our decision making method, pairwise comparisons between every two different criteria are made along all evaluated objects. During the comparison, it is maintained one counter of the number of times when the relation $R$ holds, and another counter for the dual relation.

Let $S^{\mu}_{k,l}$ be the number of cases in which the relations $R(a_{C_kO_i}, a_{C_kO_j})$ and $R(a_{C_lO_i}, a_{C_lO_j})$ are simultaneously satisfied. Let also $S^{\nu}_{k,l}$ be the number of cases in which the relations $R(a_{C_kO_i}, a_{C_kO_j})$ and its dual $\overline{R}(a_{C_lO_i}, a_{C_lO_j})$ are simultaneously satisfied. As the total number of pairwise comparisons between the object is $n(n-1)/2$, it is seen that there hold the inequalities:

$$0 \le S^{\mu}_{k,l} + S^{\nu}_{k,l} \le \frac{n(n-1)}{2}.$$

For every $k$, $l$, such that $1 \leq k \leq l \leq m$, and for $n \geq 2$ two numbers are defined:

$$\mu_{C_k,C_l} = 2\frac{S_{k,l}^{\mu}}{n(n-1)}, \quad \nu_{C_k,C_l} = 2\frac{S_{k,l}^{\nu}}{n(n-1)}.$$

The pair constructed from these two numbers plays the role of the intuitionistic fuzzy evaluation of the relations that can be established between any two criteria $C_k$ and $C_l$. In this way the index matrix $M$ that relates evaluated objects with evaluating criteria can be transformed to another index matrix $M^*$ that gives the relations among the criteria:

$$M^* = \begin{array}{c|ccc} & C_1 & \cdots & C_m \\ \hline C_1 & \langle \mu_{C_1,C_1}, \nu_{C_1,C_1} \rangle & \cdots & \langle \mu_{C_1,C_m}, \nu_{C_1,C_m} \rangle \\ \vdots & \vdots & \ddots & \vdots \\ C_m & \langle \mu_{C_m,C_1}, \nu_{C_1,C_m} \rangle & \cdots & \langle \mu_{C_m,C_m}, \nu_{C_m,C_m} \rangle \end{array}.$$

The final step of the algorithm is to determine the degrees of correlation between the criteria, depending on the user's choice of $\mu$ and $\nu$. We call these correlations between the criteria: 'positive consonance', 'negative consonance' or 'dissonance'.

Let $\alpha, \beta \in [0; 1]$ be given, so that $\alpha + \beta \leq 1$. We call that criteria $C_k$ and $C_l$ are in:

- $(\alpha, \beta)$ - positive consonance, if $\mu_{C_k,C_l} > \alpha$ and $\nu_{C_k,C_l} < \beta$;
- $(\alpha, \beta)$ - negative consonance, if $\mu_{C_k,C_l} < \beta$ and $\nu_{C_k,C_l} > \alpha$;
- $(\alpha, \beta)$ - dissonance, otherwise.

Obviously, the larger $\alpha$ and/or the smaller $\beta$, the less number of criteria may be simultaneously connected with the relation of $(\alpha, \beta)$ - positive consonance. For practical purposes, it carries the most information when either the positive or the negative consonance is as large as possible, while the cases of dissonance are less informative and can be skipped.

# 3 EXPERIMENTAL RESULTS

The metal chips briquettes preparation with good density and quality is of great importance for the efficiency of this industrial process. In the presented paper for the analysis purposes we have used experimental results of impact briquetting of grey cast iron chips.

Figure 2 shows obtained experimental results for the distance, the speed and the acceleration.

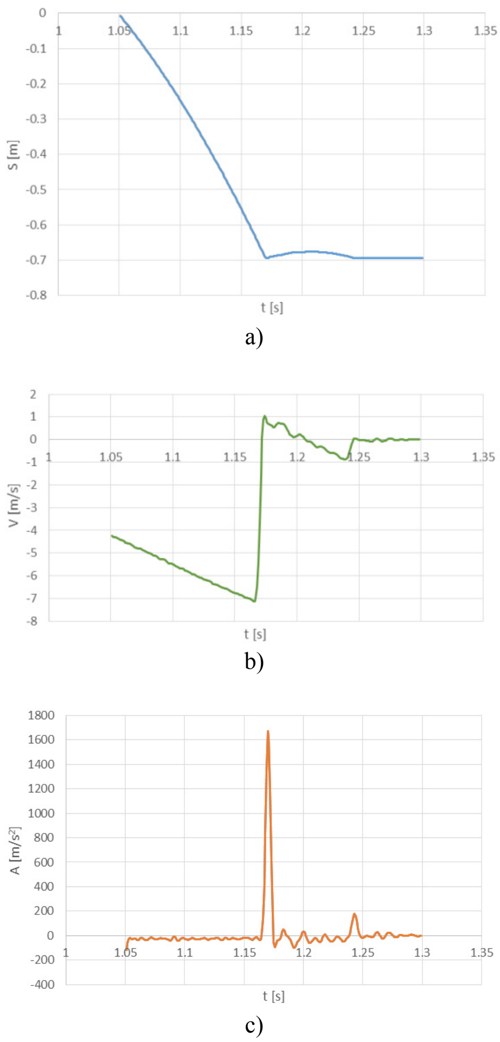


Figure 2: Distance (a), speed (b) and acceleration (c) diagrams in briquetting of grey cast iron chips.

In this paper are presented the results of impact briquetting of grey cast iron chips with rectangular shape. The average sizes are: length 25 [mm], width 15 [mm], thickness 1 [mm]. Diameter of the produced briquettes is 20 [mm], as it is the opening of the die for briquetting. Diameter of the punch is 19.6 [mm]. Density and quality of briquettes of these chips are compared with those obtained in another work of the authors using cast iron chips with smaller sizes. It has been found that if using a rectangular shape chips with a large size generates briquettes with a very low density and poor quality. From the photographs taken by X-ray tomography, it makes clear that the reason for this is the orientation of the chip in the peripheral wall of the briquettes, which does not allow of the air to escape from it. It was concluded that in order to obtain briquettes of cast iron chips with a large size, these chips must first be crushed, for example in a small ball mill. Preparation of metal chips briquettes with good density and quality is important for the efficiency of this process. The research conducted shows there is no difference in the density of the briquettes made from cleaned and not cleaned chips.

Based on the experimental research the values of eleven parameters of grey cast iron chips briquetting process have been obtained:

1 - $V_y$ – Impact speed, [m/s];
2 - $A_y$ – Impact acceleration, [m/s$^2$];
3 - $H_\Delta$ – Trimming height, [mm];
4 - $H$ – Briquette height, [cm];
5 - $D$ – Briquette diameter, [cm];
6 - $V$ – Briquette volume, [cm$^3$];
7 - $G$ – Briquette weight, [gr];
8 - $\rho$ – Briquette density, [gr/cm$^3$];
9 - $E_y$ – Impact energy, [J];
10 - $E_c$ – Impact specific energy, [J/cm$^3$];
11 - $F_y$ – Power of impact, [N].

Table 1: Membership pairs of the intuitionistic fuzzy InterCriteria correlations for the grey cast iron chips.

| μ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.6515 | 0.1969 | 0.7121 | 0.4090 | 0.6969 | 0.7121 | 0.3787 | 1 | 0.4848 | 0.6515 |
| 2 | 0.6515 | 1 | 0.51515 | 0.45454 | 0.34848 | 0.43939 | 0.48484 | 0.63636 | 0.65151 | 0.74242 | 1 |
| 3 | 0.1969 | 0.51515 | 1 | 0.24242 | 0.53030 | 0.22727 | 0.21212 | 0.66666 | 0.19697 | 0.62121 | 0.5151 |
| 4 | 0.71212 | 0.45454 | 0.24242 | 1 | 0.36363 | 0.95454 | 0.96969 | 0.36363 | 0.71212 | 0.19697 | 0.4545 |
| 5 | 0.40909 | 0.34848 | 0.53030 | 0.36363 | 1 | 0.40909 | 0.33333 | 0.28787 | 0.40909 | 0.42424 | 0.3484 |
| 6 | 0.69697 | 0.43939 | 0.22727 | 0.95454 | 0.40909 | 1 | 0.92424 | 0.31818 | 0.69697 | 0.18181 | 0.4393 |
| 7 | 0.71212 | 0.48484 | 0.21212 | 0.96969 | 0.33333 | 0.92424 | 1 | 0.39393 | 0.71212 | 0.22727 | 0.4848 |
| 8 | 0.37878 | 0.63636 | 0.66666 | 0.36363 | 0.28787 | 0.31818 | 0.39393 | 1 | 0.37878 | 0.71212 | 0.6363 |
| 9 | 1 | 0.65151 | 0.19697 | 0.71212 | 0.40909 | 0.69697 | 0.71212 | 0.37878 | 1 | 0.48484 | 0.6515 |
| 10 | 0.4848 | 0.7424 | 0.62121 | 0.19697 | 0.42424 | 0.181818 | 0.227273 | 0.712121 | 0.484848 | 1 | 0.7424 |
| 11 | 0.6515 | 1 | 0.51515 | 0.454545 | 0.348485 | 0.439394 | 0.484848 | 0.636364 | 0.651515 | 0.742424 | 1 |

These have been analysed applying InterCriteria decision making approach. The results are presented in Table 1.

The results show a strong relation between the parameter pairs: 1 (‘Impact speed‘) – 4 (‘Briquette height‘); 1 (‘Impact speed‘) – 7 (‘Briquette weight‘); 2 (‘Impact acceleration‘) – 10 (‘Impact specific energy‘); 4 (‘Briquette height‘) – 6 (‘Briquette volume‘); 4 (‘Briquette height‘) – 7 (‘Briquette weight‘); 4 (‘Briquette height‘) – 9 (‘Impact energy‘); 6 (‘Briquette volume‘) – 7 (‘Briquette weight‘); 7 (‘Briquette weight‘) – 9 (‘Impact energy‘); 8 (‘Briquette density‘) – 10 (‘Impact specific energy‘).

Part of these relations is due to the specific physical properties of the briquettes, which confirms the reliability of the proposed InterCriteria decision making approach. The benefit here is that this allows for finding strong dependencies as well as such where the relations are not so visible.

The geometrical visualisation of the InterCriteria correlations for the case of iron powder briquette onto the intuitionistic fuzzy interpretational triangle is shown on Figure 3.

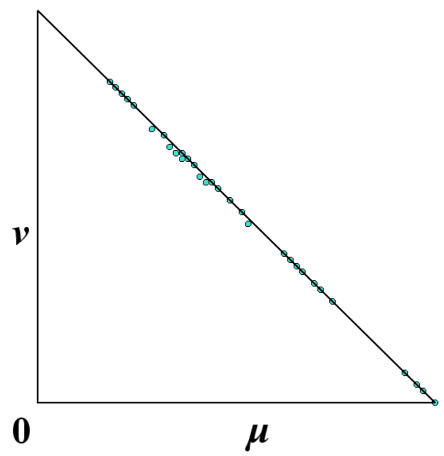


Figure 3: Geometrical visualisation of the InterCriteria correlations for the case of iron powder briquette onto the intuitionistic fuzzy interpretational triangle.

## 4 CONCLUSION

During the experiments it was seen that when briquetting grey cast iron chips increasing the impact specific energy to some point this increases the density, but further increase leads to a decrease in briquettes density. The conclusion that can be made is that this is being influenced by the content of carbon in the iron-carbon alloys.

The present paper proves the application of this original InterCriteria decision making approach, which eases the analysis if the relations between the criteria, giving better production quality.

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