# Using Semantically Annotated Models for Pattern-Based Process Analysis


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# USING SEMANTICALLY ANNOTATED MODELS FOR PATTERN-BASED PROCESS ANALYSIS

***Abstract***
*Support of processes by appropriate Information and Communication Technology (ICT) is a key requisite to persist in an environment characterised by high specialisation and cooperative service production – also in the public sector. This paper describes a method for pattern-based semantic process analysis including its prototypical implementation. The objective is the identification of weaknesses as well as the analysis of ICT impact with regards to reducing or eliminating these weaknesses. Using this approach, business analysts can rely on an extensible and flexible tool for querying in a natural language close way and analysing process models by means of weakness patterns.*

## 1. Introduction

Management of business processes has emerged to a fundamental concept for organisational transformation in the information age. Support of processes by appropriate Information and Communication Technology (ICT) is a key requisite to persist in today's intensified competition and global environment which is characterised by high specialisation and cooperative service production. Thus, ICT has been established in many areas of business processes supporting information availability independently from time and place. Examples are electronic procurement and commerce (inter-organisational view) or decision support systems for controlling and management purposes (intra-organisational view). However, in business areas which are characterised by less formalisation of knowledge (such as documentations of business processes) ICT-related automation does not play such an important role yet. Although business processes are electronically documented in many industries, the quality of the formalised knowledge representation depends to a large extent on the experiences and perceptions of modellers and analysts. Both, modelling and analysis are still impaired by a multifaceted variety of inconsistent terminologies, incompatible notations, inadequate levels of detail and abstraction as well as unclear interpretation and lacks of comparability, integrity or topicality [Curtis et al. 1992, Lin 2008]. ICT-supported automation of modelling and analysis is thus limited to syntactical checks of consistency. Analysis of semantic model quality (validity of meaning, completeness of content) [Lindland et al. 1994] remains a manual task of internal or external human specialists with the respective consequences on costs and heterogeneity of model quality. These issues are increasing in cooperative process environments where different people have to agree on a common understanding and different parts of one model have to be joined for comprehensive analyses [Lippe et al. 2005]. A characteristic example is the fragmented, cross-organisational service production in public administrations [Rainey et al. 1976, Schiflett/Zey 1990] where formalised documentation of internal procedures is almost absent [Baacke et al. 2007b]. Considering the high number of processes and their increasing complexity, the identification of – often organisation-wide – optimisation potentials (e.g. by introduction of supporting ICT) and the analysis of expectable impacts are nearly impossible within such an undocumented process landscape, relating to the overall set of processes within an organisation. Hence, semantically enriched formalisation of knowledge by respective modelling techniques is considered not only to improve effectiveness and efficiency of modelling but especially to enhance the practical value of information extensively.

For these reasons, the importance of semantics in managing business process knowledge has been recognised and became subject of various scientific and practical investigations in the private and public sector [Hepp et al. 2005, Celino et al. 2007, Lin 2008]. An example for such research is the EU-funded project PICTURE [PICTURE 2006] which addresses the low diffusion of process modelling in public administrations by developing an approach for collaborative process modelling based on semantically enriched activity descriptions: process building blocks (PBBs). Based on their standardised semantics, process models can be analysed automatically not only with regards to semantic plausibility, consistency or completeness but also regarding characteristic weakness patterns and appropriate optimisation potentials. As significant effects become visible when analysis is automatically executed, the project not only aims at the development of the respective methods but also at their prototypical implementation.

In completion to existing publications about the methodological parts [Baacke et al. 2007a, Becker et al. 2007, Baacke et al. 2008], this article focuses on the technical realisation of semantic modelling and analysis. For that purpose, after an overview about the research approach in the subsequent section, in section 3 the underlying conceptual requirements will be briefly introduced. In order to cover both aspects the modelling as well as the analysis part of the project, section 4 discusses the practical implementation of process documentation based on semantically standardised PBBs while section 5 presents the practical implementation of the automated process analysis using process patterns and semantic reasoning mechanisms. Finally, the main findings as well as the questions for further research are documented in section 6.

## 2. Research Methodology

As the development of a sophisticated, computer-assisted approach for process modelling and analysis is a rather pertinent and practical endeavour, engaged research is needed in order to provide rigorous solutions for this relevant problem. A theoretical basis that serves both relevancy and rigour and requires intense investigation is that of design research [Darke et al. 1998]. Following Peffers et al. [Peffers et al. 2006], the design research process typically consists of six phases (cp. *Figure 1*).

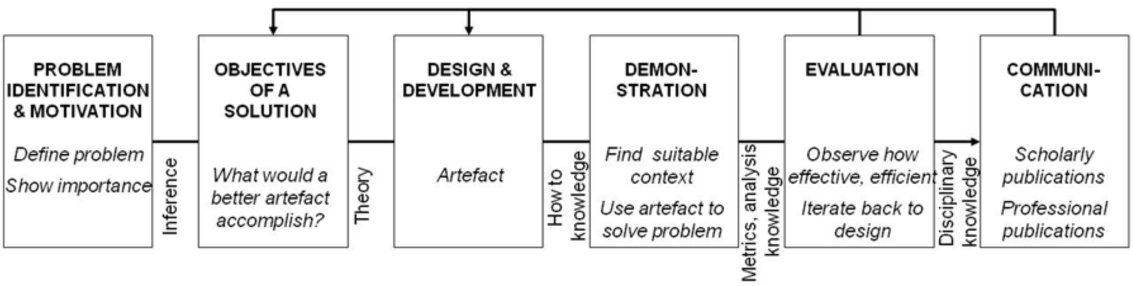


**Figure 1: Design science research process model [Peffers et al. 2006]**

Usually research is initiated by a "need and require intention" [Purao 2002], i.e. a practical problem is identified and its importance satisfactorily demonstrated. Unlike natural sciences, which try to explain and predict behavioural aspects of reality by developing and verifying theories, design-oriented research aims at building and evaluating innovative artefacts, in order to extend existing capability limitations [March/Smith 1995]. Hence, it is considered a problem-oriented approach [Hevner et al. 2004]. Depending on the problem area, the objectives of the solution and the appropriate requirements for solving the problem are specified. Based on this specification, a solution of the problem is developed accordingly. In order to ensure the quality – that is a wellbalanced combination of relevancy and rigour – of the new artefact(s), a demonstration of the functional capability, and an evaluation of the effectiveness and efficiency of the problem solving is needed. Finally, it is also incumbent upon design researchers to further knowledge that aids to enhance the “current understanding of either how information technologies are managed (so that they can be appropriately used within organisations) or how information technologies are used (and the implications of such use) within organisations” [Zmud 1997]. Therefore partial and final solutions are communicated to technology-oriented as well as management-oriented audiences so that they can “take advantage of the benefits offered by the artefact” [Hevner et al. 2004]. Artefacts represent the final results of a design process. They can be characterised as constructs, models, methods or instantiations [March/Smith 1995]. In this case a number of artefacts have been developed. Starting point was the definition of the essential constructs for semantic modelling and process analysis. This served as basis for the construction of the overall methodology which represents the actual artefact. According to the six phases of the design research process, the artefact should be applied to solve addressed problems in a suitable context (demonstration phase) [Peffers et al. 2006]. Hence, the methodology has been prototypically implemented in form of an instantiation (software tool) which enables a demonstration of the functional capability of the artefacts, keeping in mind that further evaluation activities have to be conducted. This contribution describes the implementation of the overall method (consisting of the modelling and analysis part).

## 3. Conceptual Requirements

The overall objective of the presented methodology is the identification of weaknesses (fields for optimisation) as well as the quantitative and qualitative analysis of ICT introduction which is considered to potentially reduce or eliminate a weakness (impact of optimisation) [Baacke et al. 2008]. Prerequisite for such analyses is extensive knowledge about internal organisational and procedural structures which is documented by semantically enriched process models. Thus, the approach can be divided into the two phases model and analyse. Initially, the as-is situation of a process landscape has to be captured through respective models (phase 1). Subsequently potential sources of inefficiency can be identified through measurement on the modelled process landscape. Furthermore, beneficial ICT is analysed with respect to its impact on such process weaknesses (phase 2).

In order to realize the objective of being able to computationally identify and analyse weaknesses in processes a number of requirements and constraints need to be met by the developed method that will be described in the following. The described approach is required to be able to elicit the relevant knowledge from process modellers in a form that can subsequently be analysed for potential ICT impact. It requires gathering information on control flow, message flow, document flow as well as responsibilities and other process and activity related information such as number of cases of a certain process or cycle times. This relates to the ability to transfer internalised knowledge about processes into explicit codification of knowledge that can be shared [Nonaka 1991] and in the particular scenario of our research be analysed for optimisation potential. Pfeiffer [Pfeiffer 2007] argues that “in large modeling projects the acquisition of relevant domain knowledge is performed in a distributed manner” which often results in models that contain incompatible use of vocabulary, as well as differing grades of abstraction and level of detail [Hadar/Soffer 2006]. Hence in order to realise comparability of models, which is a prerequisite of computational analysis, the method described in this paper has taken the approach of constructing a “domain specific conceptual modelling language” [Pfeiffer 2007]. It thereby reduces complexity, and allows for structured capturing of information required for the ICT impact analysis based on a predefined yet customisable vocabulary for process description. The subsequent section describes relevant aspects of the modelling language and method prior to discussing in detail the conceptual and technical realisation of the ICT impact analysis.

## 4. Capturing of Semantic Process Information

In order to obtain formalised process descriptions which can be analysed automatically in phase 2, the main objective of the first phase is semantically annotated process modelling. Assuming that processes in public administrations are representative for service production in collaborative environments (cp. introductory remarks) and considering the characteristic that a high number of various processes usually consist of a small number of recurring activities, the bottom-up modelling approach of *PBB composition* was selected [Baacke et al. 2007b]. This approach suggests that recurring activities are depicted by an adequate set of generic PBBs whose composition results in complete process chains.

Due to the heterogeneity of existing process documentations, the identification of a minimal number of generic PBBs that enable a semantically standardised depiction of typical administrational processes is a challenge. As a result of the heterogeneity of existing process models which have been used for identification of typical PBBs a high number of PBB candidates were extracted which complicates efficient identification and selection of appropriate PBBs during the modelling process. In order to reduce the number of PBBs, a higher level of abstraction was needed which has been reached by generalising PBB candidates. This generalisation was achieved by distinguishing between the core activity and the object that is processed by the activity [Baacke et al. 2007a]. An example is the PBB candidate "send a letter" that can be divided into the activity "send" and the processed object (PO) "letter". However, information limited on activities is not sufficient to create automatically analysable processes. In fact, after having chosen suitable PBBs during the modelling phase, specialisation is needed. One possibility to detail PBBs is the specification of attributes such as processing time, sender and communication channel (for the PBB "receive"), or number of copies (for the PBBs "copy" and "print"). Also POs can be specified by further attributes such as media (e.g. paper-based or electronically) and number of pages. Furthermore, the modelling method captures information about responsible organisational units as well as about existing ICT applications (cp. [Baacke et al. 2007a, Baacke et al. 2008] for an overview of the set of PBBs and attributes defined in PICTURE). As the developed modelling approach is not limited to a specific notation, a broad and flexible usage by different organisations and in various tools is enabled. According to the fourth step (evaluation) of the design science research process (cp. *Figure 1*), about 200 processes have been modelled so far by different public administrations on the basis of PBBs based on the prototypical implementation. The results of this evaluation indicate that PBBs improve both effectiveness and efficiency of process modelling.

Based on the conceptual model for process documentation and analysis shown in *Figure 2*, a procedure model for process modelling using a domain-specific language has been designed and implemented in the prototype. In generic modelling approaches which apply languages such as the Event-Driven Process Chain or the Business Process Modelling Notation (BPMN) modelling is generally carried out by individual experts that are in charge of the complete procedure from objective definition up to model analysis. In contrast, if using a domain-specific language individual stakeholders/experts can be involved to provide specific semantically annotated information in different phases of the modelling procedure.

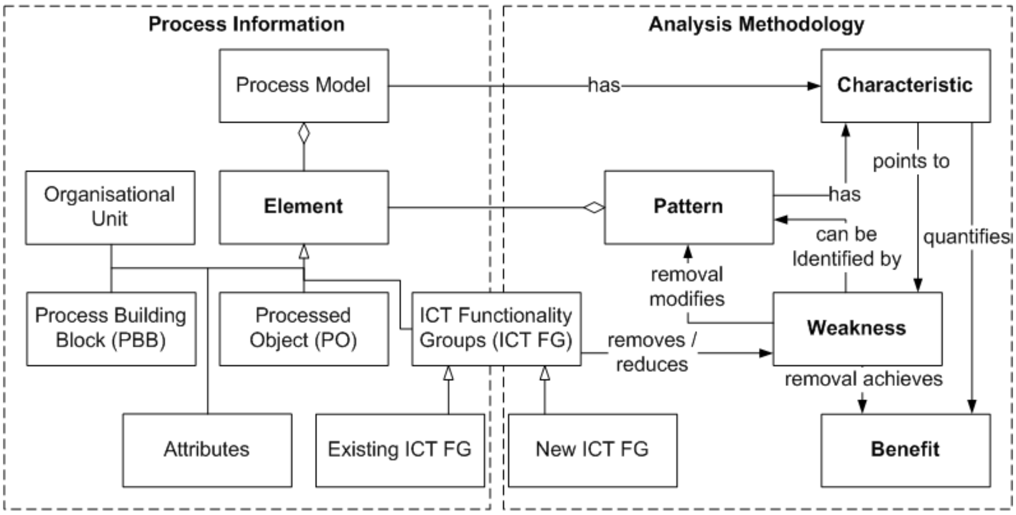


**Figure 2: Conceptual model for process documentation and analysis [Baacke et al. 2008]**

The presented approach thereby identifies two steps: modelling preparation and modelling. During modelling preparation, the modelling objectives can be applied to configure the domain-specific language to only capture relevant information. If for example quality issues are prioritised over performance issues, PBB attributes capturing information about e.g. processing time or idle time can be disabled. In addition, information that is necessary for a sound analysis can be defined as mandatory. As a result, during the modelling step, modellers are only required and capable of providing relevant information which reduces complexity of the models. In addition the predefined vocabulary of PBBs and respective attributes (cp. [Baacke et al. 2008]) enables and supports distributed modelling as it avoids ambiguity or incompatibility of process models or sub-models (e.g. of a sub-process) that result e.g. from abstraction conflicts, synonym conflicts or detail conflicts [Pfeiffer/Gehlert 2005].

Based upon the captured process flow in phase 1, process characteristics can be measured and potential weaknesses can be identified. Some examples will be presented in the subsequent section. The analysis is thereby not limited to the scope of individual processes; instead the analysis can be carried out over the whole process landscape. The focus of the methodology lays on the elimination of typical weaknesses, such as media breaks or inefficient communication channels, through the support of ICT. In order to analyse appropriate ICT support for existing weaknesses, concrete ICT services have been assigned. Therefore, a set of generic front-office and back-office related ICT functionality groups (ICT FGs) were developed [Picture 2007]. The conceptualisation of the resulting overall methodology that integrates the previously described two phases is shown in *Figure 2*. The subsequent section describes how a computational impact analysis (phase 2) can be carried out based on processes that are described using the modelling approach of a domain specific modelling language discussed in this section.

## 5. Pattern-Based Analysis

After elucidating all relevant elements for the modelling approach, the following section focuses on the semantic analysis of the previously described business process models and impact measurement of relevant ICT functionality groups. First, the conceptual foundations of the analysis and measurement approach are introduced; second, its implementation concepts and realisation will be presented. The overall ICT impact analysis approach of PICTURE is illustrated on the right side of the meta model in *Figure 2*. The analysis method encompasses the core elements “Pattern”, "Weakness", "Benefit", and "Characteristic", whereas the latter one will be discarded in the following as the focus of this paper lays on the pattern based identification of weaknesses in process models with the help of semantic reasoning and ontologies.

Patterns are considered hereby as arbitrary combinations of elements used for the process modelling including PBBs, POs, organisational units, and ICT FGs with all their appropriate attributes. Weaknesses can be identified by means of patterns which are specified by business analysts with domain expertise. By introducing applicable ICT FGs, accordant weaknesses in business processes can be reduced or even removed which results in benefits for single processes or for the overall process landscape. A detailed specification of the meta model of the ICT impact analysis can be found in [Baacke et al. 2007a, Baacke et al. 2008]. The meta model indicates the complexity of relationships between the elements used for the PICTURE modelling and analysis approach. However, relationships such as "isDirectPredecessorOf" or "hasProcessedObject" between single entities of the process information area are not included in *Figure 2*. For a comprehensive analysis a business analyst relies on an extensible and flexible tool support of querying and analysing the process models using these relationships. Thus, the implementation concept for the PICTURE prototype has been designed to be free from any constraints, such as hard coded queries (e.g. complex table joins) or analysis patterns in order to guarantee a flexible analysis. As the core element for fulfilling these requirements, an ontology has been designed as the central data structure for all analysis tasks of the PICTURE prototype. Based on a standardised terminology of concepts as well as relationships between these concepts an ontology represents a specific knowledge domain [Gruber 1992, Hesse 2002]. Gruber [Gruber 1992] characterises this fact in his definition of ontologies as an "explicit formal specification of a shared conceptualization". Through their flexible management of various, complex relationships ontologies allow therefore the modification of existing patterns as well as the introduction of new ones in a natural language close definition approach for the business analyst. The ontology for the PICTURE prototype has been designed and engineered using the Web Ontology Language (OWL) Description Logic (DL) [W3C 2004].

In addition to the management of relationships between entities, the inference concept (which is feasible by the application of an ontology) proved to be valuable for the PICTURE analysis method as well. In the domain of semantic research, inference is often paraphrased as the fact that "complex concepts can […] be built up in definitions out of simpler concepts." [Horridge et al. 2004]. This essentially means that additional information which is not explicitly stated can be inferred from existing knowledge in an ontology model. For instance, a semantic reasoner can identify any PBB sequence of interest, regardless of the concrete succession of the PBBs (cp. *Figure 3*) – a task that would be rather complex to handle via usual database queries. By means of introducing a transitive OWL ObjectProperty "isSuccessorOf" of a PBB, the complex computation is carried out by the semantic reasoner without the need to define any further complex algorithms neither for users nor for developers of the tool.

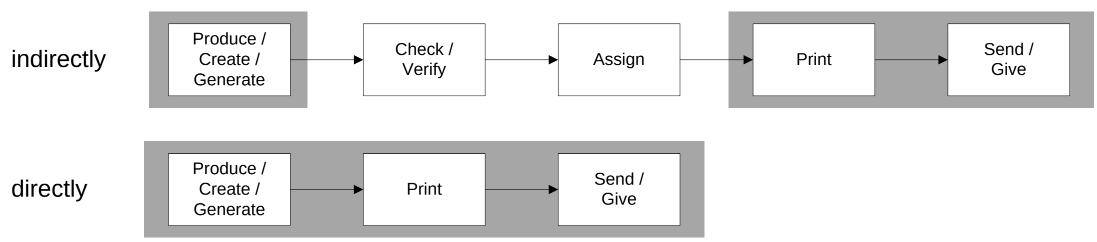


**Figure 3: Example of a PBB sequence of interest**

As instrument for ontology processing and reasoning the open-source Java framework *Jena2 Semantic Web Framework* [Packard 2007, Reynolds 2007] has been chosen. As an environment for semantic web applications it allows processing of semantic formalisation standards such as Resource Description Framework (RDF), Resource Description Framework Schema (RDFS), and OWL. The Jena 2 Framework encompasses - amongst others - a Jena Ontology API (for processing and generating ontologies), a Jena Inference API (for accessing included reasoning engines), and several reasoning engines (e.g. OWL Reasoner, DARPA Agent Markup Language (DAML) Reasoner, and Generic Rule Reasoner). For the PICTURE prototype the Generic Rule Reasoner has been used because of its rule-based functionality and its performance.

*Figure 4* shows the overall architecture and reasoning approach for the pattern analysis. First, the original model containing all relevant semantic information of the process models is processed into an OWL ontology and transferred to the reasoner. Second, rules are passed to the reasoner. The rules which are specified in a Jena Rule specific syntax contain patterns that allow the identification of weaknesses within the process models. The Jena Rule syntax formalises RDF(S) or OWL actions based on a RDF triple set for e.g. defining new individuals, properties, or classes into the inferred model [Reynolds 2007]. RDF triples represent hereby relationships between classes and individuals of an ontology. The triples follow a "subject – predicate – object" structure, e.g. "Create" – "isDirectPredecessorOf" – "Print". Finally, the reasoner enhances the information of the original model with the reasoning results into the inferred model. A more detailed description of the inference in context of the pattern-based process analysis will be given in the following section.

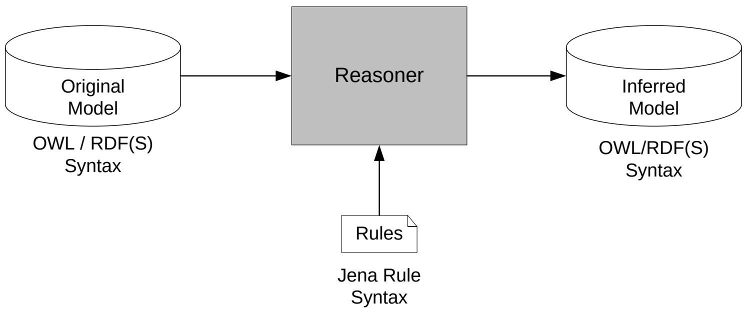


**Figure 4: Inference with the Jena Generic Rule Reasoner**

The contextual design of the PICTURE ontology is based on the persistence layer for the process modelling including previously described elements. For the implementation it has been differentiated between various structural forms of the ontology – the *static model*, the *dynamic model* and the *individual ontology*. The static model represents the knowledge of the domain of public administrations in general including main elements (classes) such as processes, types of PBBs or types of POs. The dynamic model, which imports the static model, is associated with one specific public administration and acts as a customised template, e.g. if a specific public administration renames the PBB "Create" to "Generate". The third component of the overall PICTURE ontology is the individual ontology encompassing the static and dynamic model ontology. The individual ontology stores all relevant information of the process models of the public administration for the pattern analysis.

By means of the PICTURE ontology all pattern analysis relevant elements can be formalised in the OWL DL representation. As mentioned above the patterns which identify weaknesses in process models are described and specified via RDF triples in the Jena Rule Syntax. The rules contain a condition as well as an action part, which is triggered if the condition of the rule (in form of a RDF query with RDF triples) matches. While each positive query of the condition is a pattern match in the PICTURE individual ontology, the action which is also represented as RDF triple set (but not as a query) creates new RDF triples in the PICTURE inferred ontology (cp. *Figure 4*).

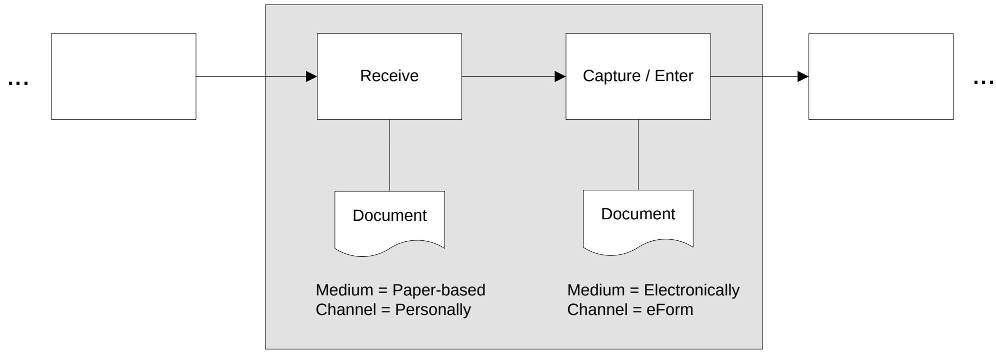


**Figure 5: Media break as combination of PBBs and POs**

The exemplary pattern type shown in *Figure 5* contains a sequence of the PBB types “Receive” and “Capture/Enter”. Both of the PBBs have the same PO (cp. *Table 1*: variable ?3 equals variable ?4), whereas the medium of the document is first paper-based and afterwards electronically. This medium change within a process model is an identifier for a media break – one of the most known structural process weaknesses in the domain of public administrations. The according RDF triples describing the pattern (the condition of the rule) are listed in *Table 1*. Variables in the RDF triples have a “?” as prefix, objects of the PICTURE ontology are identified via the prefix “p”, e.g. “p1:isDirectPredecessorOf”. In case of a positive query response the variables are filled with values.

**Table 1: RDF triple representation of a media break pattern**

| **Subject** | **Predicate** | **Object** |
|---|---|---|
| ?1 | rdf:type | p1:Receive |
| ?2 | rdf:type | p1:Capture / Enter |
| ?1 | p1:isDirectPredecessorOf | ?2 |
| ?3 | rdf:type | p1:PO_Document |
| ?4 | rdf:type | p1:PO_Document |
| ?1 | p1:hasProcessedObject | ?3 |
| ?2 | p1:hasProcessedObject | ?4 |
| ?3 | equals | ?4 |
| ?3 | p1:Medium | ‘Paper-based’ |
| ?4 | p1:Medium | ‘Electronically’ |

Having identified a weakness within a process model by means of the pattern-based technique, the business analyst automatically gets a recommendation of appropriate ICT FGs by the PICTURE prototype. The proposed ICT FGs address exactly the identified weakness (in the above given example of a media break, e.g. an object management system) in terms of reducing or even eliminating the weakness. In addition to the recommendation of ICT FGs, the prototype gives a first quantification of the benefit(s) (e.g. reduced process time, reduced consumables etc.) if recommended ICT FGs will be used [Baacke et al. 2008]. This quantification is based on attributes which are specified during the process modelling. A quantification of benefits such as reduced use of consumables is realised by multiplying paper costs, number of printed pages per process and number of processes where the weakness of a media break has been identified.

## 6. Conclusion and Outlook

In this contribution a technical realisation of semantic process modelling and analysis is described. Based on the methodological foundation of composing standardised process building blocks, processed objects, ICT functionalities and respective attributes (phase 1), resulting documentations can be evaluated regarding typical process patterns, e.g. representing organisational weaknesses, and supporting ICT as well as potential impacts (phase 2). While the underlying modelling method primarily addresses a broader diffusion and standardisation of modelling techniques in complex, collaborative process environments, the prototypical automation of analysis provides comprehensive and flexibly configurable mechanisms to improve model consistency and plausibility as well as to identify procedural deficiencies and optimisation potentials.

The developed prototype was used by domain experts to prove the theoretical concepts in real-world scenarios. Regarding the modelling support, predefined PBBs significantly reduced the variety of inconsistent terminologies, inadequate levels of detail as well as the lacks of comparability and integrity. Furthermore, comprehension of process documentations was improved as a common understanding of activities and their logical sequencing has been established. This is especially valuable in collaborative environments where perceptions of very different people have to be aligned and distributed model fragments have to be joined. After a short training period, modellers experienced a considerable improvement of modelling effectiveness and efficiency.
Regarding the analysis part, the formalisation of weaknesses through semantic patterns, the automated, organisation-wide identification of deficiencies and respective optimisation potentials (e.g. by introduction of supporting ICT) as well as the analysis of expectable impacts are considered a capable and very flexible approach. Generated reports support business analysts and decision makers in evaluating the benefits of organisational or technical innovations.

Although the prototypical implementation only proved the applicability of the methods in the public sector, an adoption of this approach for other industries (e.g. health care) promises similar advantages. Thus, future research will focus on domain-specific modifications of PBBs and weakness patterns for other industries and domains.

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