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Using Ontology for the Representational Analysis of Process Modelling Techniques

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Abstract: Selecting an appropriate business process modelling technique forms an important task within the methodological challenges of a business process management project. While a plethora of available techniques has been developed over the last decades, there is an obvious shortage of well-accepted reference frameworks that can be used to evaluate and compare the capabilities of the different techniques. Academic progress has been made at least in the area of representational analyses that use ontology as a benchmark for such evaluations. This paper reflects on the comprehensive experiences with the application of a model based on the Bunge ontology in this context. A brief overview of the underlying research model characterizes the different steps in such a research project. A comparative summary of previous representational analyses of process modelling techniques over time gives insights into the relative maturity of selected process modelling techniques. Based on these experiences suggestions are made as to where ontology-based representational analyses could be further developed and what limitations are inherent to such analyses.

Keywords: Business Process Management, Representational Analysis, Ontology, Business Process Modelling.

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1 INTRODUCTION

Business Process Management (BPM) has been identified as a top business priority, and building business process capability is seen as a major challenge for senior executives in the coming years (Gartner Group, 2006). The interest in BPM has, amongst others, led to an increased popularity of business process modelling (Davies *et al.*, 2006). Due to the demand for a more disciplined approach for Business Process Management, many organizations have been motivated to make substantial investments in process modelling initiatives. This situation in turn has triggered significant related academic and commercial work aiming towards advanced business process modelling solutions. Consequently, a competitive market is providing a plethora of tools and methods for process modelling initiatives (Miers *et al.*, 2006).

Process modelling techniques range nowadays from simple flowcharting techniques (American National Standards Institute, 1970) to business modelling approaches such as Event-driven Process Chains (Keller *et al.*, 1992) and software engineering-driven techniques such as UML (Fowler, 2004) to formalized and academically studied techniques such as Petri nets (Petri, 1962) and its dialects. One of the most recent proposals for a new process modelling technique is the Business Process Modeling Notation (BPMN). BPMN was released in May 2004, adopted by OMG in February 2006 for standardization purposes (BPMI.org and OMG, 2006b), and has since received significant attention.

The emergence of such new process modelling techniques leads to the question *if there are actual signs of an increasing maturity within the capabilities of process modelling techniques*. More specifically, there is increasing demand to shift the academic resources committed to the development of new and further extensions of existing process modelling techniques to the critical evaluation and comparison of the already available set of modelling techniques (Moody, 2005; Nelson *et al.*, 2005). This move is a pre-requisite for an evolving research discipline that builds on the existing body of knowledge, has an awareness for the remaining open challenges, and is guided by a methodological procedure in its future research efforts (Kuhn, 1962; Keen, 1980; Weber, 1997). This scenario is particularly the case in Information Systems (IS) design research where the analysis of the strengths and weaknesses of existing methods can be used as the basis for developing new and improved methods (Bubenko, 1986).

The large selection of currently available process modelling techniques, however, stands in sharp contrast to the paucity of evaluation frameworks that can be used for the task of evaluating and comparing those modelling techniques. A complete analysis of all facets of a process modelling technique is a significant task and would include, amongst others, its expressive power, the consistency and correctness of its meta-model, the perceived intuitiveness of its notation, the available tool support, the existing reference models expressed in this technique (e.g., ITIL, SCOR), and the like. While there is unfortunately not one single framework that facilitates such a comprehensive analysis, reasonably mature research has emerged over the last decade with a focus on the *representational capabilities* and the expressive power of modelling techniques. Such frameworks have been developed either inductively from observable practice or deductively from applicable theories.

A prominent example of an inductively developed framework is the set of workflow patterns developed by van der Aalst *et al.* (2003). The development of this framework was triggered by a bottom-up analysis and comparison of fifteen workflow management systems during 2000 and 2001, with focus on their underlying modelling techniques. The goal was to bring insights into the expressive power of the underlying languages and thereby outline similarities and differences between the analyzed systems. The workflow patterns research initially was focused on the development of a minimal set of control flow patterns that in composition constitute possible control flow logic. By now, this research has also explored related perspectives and a first set of data (Russell *et al.*, 2005a) and resource patterns (Russell *et al.*, 2005b) have been proposed. The workflow pattern-based evaluation of various process modelling techniques, such as BPEL4WS (Wohed *et al.*, 2003), UML Activity Diagrams (Wohed *et al.*, 2005), and BPMN (Wohed *et al.*, 2006), is based on the assumption that a more complete coverage of these patterns leads to techniques and systems with advanced expressive power.

On the other hand, an increasingly popular evaluation framework that has been derived through deductive research methods is representational analysis based on foundational ontologies. Unlike the high number of ontologies that have been proposed in the AI discipline for various domains, see e.g., (Gruber, 1993; Uschold and Grüninger, 1996), foundational (upper) ontologies are well-grounded in thorough philosophical research.

Of those two types of frameworks, this paper is focused on the latter, i.e., representational analyses of process modelling techniques based on ontologies. Specifically, we concentrate on a rapidly emerging body of research that is grounded in a well-established, mathematically defined ontology proposed by Mario Bunge (1977; 1979). This ontology has been adapted by Weber and Wand (1988) into a theory of representation that is closer to the demands and terminology of the Information Systems community. This theory of representation became widely known as the Bunge-Wand-Weber (BWW) representation model.

The deployment of the BWW representation model in studies on the representational capabilities of process modelling techniques can be justified on at least three premises. First, unlike many other foundational theories based on ontology, the BWW model has been derived with the Information Systems discipline in mind (Wand and Weber, 1990a, p. 124). Second, while the BWW model does not denote a unique case of IS-specific ontologies, refer, for instance, to (Guizzardi, 2005), there is an established track record and demonstrated usefulness of representational analyses of modelling techniques using the BWW representation model. Third, the BWW model officiates as an upper ontology for the modelling of Information Systems, and the foundational character and comprehensive scope allows for wide applicability.

The aim of this paper is to explore and discuss the benefits and limitations of such representational analyses in the context of process modelling techniques. Thereby, both developers and users may be able to pinpoint, scrutinize and compare potential representational shortcomings of current specifications in order to derive more sophisticated, revised techniques. To address this objective, we studied previous representational analyses of process modelling techniques and complemented this body of research with our own analysis of Petri nets and BPMN in order to achieve a reasonably complete set of evaluated process modelling techniques. Based on the consolidation of these studies and our own experiences, we present a research model that can serve as a guideline for applying representation theory in studies of modelling techniques. We discuss the different steps involved in such studies and present some guidelines for each of them. We also show how representational analysis can be used to draw conclusions on the evolution of process modelling techniques over time, and discuss perils and limitations related to representational analysis.

The remainder of this paper is structured as follows. The next section gives an overview of the general research model which underlies this type of evaluation. Next, we briefly introduce the selected theoretical model and summarize in section 3 previous research on representational analyses of process modelling techniques. Section 4 compares the outcomes of these analyses and studies signs of increasing process modelling capabilities over time. Section 5 critically reflects on the limitations of such analyses. We conclude in section 6 with a proposed research agenda that might give interested researchers inspirations for related work.

2 A RESEARCH MODEL FOR REPRESENTATIONAL ANALYSES

Before we provide an overview of the outcomes of previous representational analyses of process modelling techniques, it is necessary to understand and appreciate the overall research model that underlies such evaluations.

The theoretical foundation and rigor of this type of research is derived from the selected foundational ontology. Research based on the BWW models can be traced back to the comprehensive and detailed work by Mario Bunge (1977; 1979) and its accomplishments. The initial and ongoing development of such ontologies, and the comparison of different foundational ontologies, is a challenging task that is located in the discipline of philosophy and has its roots in Aristotle's foundational work on metaphysics (Aristotle, 1991).

The philosophical nature of Bunge's ontology, its terminology and the overall scope, however, are not very conducive to application in the context of Information Systems or more specifically Business Process Management and modelling. Nevertheless, Wand and Weber saw the potential of Bunge's work to the discipline of Information Systems:

"*We have chosen to work with Bunge's ontology because it deals directly with concepts relevant to the information systems and computer science domains (e.g. systems, subsystems and couplings). Moreover, Bunge's ontology is better developed and better formalized than any others we have encountered*". (Wand and Weber, 1995, p. 209)

While this justification in itself bears little merit in terms of a rigorous motivation for the use of this ontology, its adoption by Wand and Weber (1990b; 1993; 1995) nevertheless facilitated a wider uptake of this theoretical model within the Information Systems community. The Bunge-Wand-Weber models actually comprise three models (Wand and Weber, 1995; Weber, 1997), *viz.*, the representation model, the state-tracking model and the decomposition model. The representation model is typically used for the evaluation of process modelling techniques.

Wand and Weber's work based on Bunge's theory is not the only case of ontology-based research. Today, interest in, and applicability of ontology, extends to areas far beyond conceptual modelling. The usefulness of ontology as a theoretical foundation for knowledge representation and natural language processing is a fervently debated topic in the artificial intelligence research community (Guarino and Welty, 2002). Holsapple and Joshi (2002) for example, argue the importance of ontology in the emergent era of knowledge-based organizations and the conduct of knowledge management in those organizations. Kim (2002) shows how ontology can be engineered to support the first phase of the evolution of the 'semantic Web'. As these selected examples show, the theory of ontology has emerged as a fruitful base from which a wide range of theoretical contributions in the IS and related disciplines stem from.

It must be noted, however, that the use of ontology in IS research is not undisputed. The BWW model, for instance, has sometimes been subjected to criticism (for a comprehensive discussion refer, for instance to (Kautz *et al.*, 2006). We do not wish to engage in this debate and instead merely point to the various examples of testing and validation that the model has undergone over time (Wand and Weber, 2006). In conclusion, its widespread adoption and extent of validation have motivated our selection of the BWW model.

Independent from the stream of ontological research, a wide variety of process modelling techniques has been developed over the years based on different theoretical foundations and for different purposes. The process of developing a new process modelling technique is less understood than the classical software engineering process and can be regarded as not sufficiently researched. In the process of requirements engineering for Process-aware Information Systems, for example, various stakeholders are confronted with the need to represent the requirements in a conceptual form (Dumas *et al.*, 2005). Often, however, they use modelling techniques that do not possess an underlying conceptual structure on which to base such models or that have been proposed with limited consistent theoretical foundation underlying their conception or development (Floyd, 1986; van der Aalst, 2003). Moreover, the wide range of purposes with demand for process modelling techniques (e.g., process improvement, Web services, Enterprise Systems implementations, workflow management, compliance management) and commercial opportunities in this area further contributed to an inflation of individually developed modelling techniques and corresponding tools. Clearly, what is needed is a theoretical basis to assist as a reference benchmark in the evaluation and comparison of available process modelling techniques. Given the existence of such theory, it would not only be possible to evaluate these techniques, but also to determine if the discipline of process modelling is building on previous knowledge, and if new techniques really denote an actual improvement.

The process of using the BWW representation model as a type of reference benchmark for the evaluation of the representational capabilities of a modelling technique forms the core of the research method of representational analysis. In this process step, the constructs of the BWW representation model (e.g., thing, event, transformation) are compared with the language constructs of the process modelling technique (e.g. event, activity, actor). The basic assumption is that any deviation from a 1-1 relationship between the corresponding constructs in the representation model and the modelling technique leads to a situation of representational deficiency and/or ambiguity in the use of the technique potentially causing confusion to the end users.

The set of BWW constructs is well defined in various languages. Wand and Weber (1990b), for instance, use set theory to formalize the set of constructs, and Rosemann and Green (2002) developed a semi-formal description of the set of BWW constructs by means of a meta-model using the

Extended Entity-Relationship (EER) modelling notation (Chen, 1976). We do not seek to recite the specification of the representation model in this article and instead refer the interested reader to the extensive formalization described, for instance, in (Wand and Weber, 1990b; 1995; Weber, 1997).

While the model itself is well defined, the process of applying the representation model constructs as part of a representational analysis is less specified. It was only recently that more advanced procedural models have been proposed (Rosemann *et al.*, 2005) that guide researchers through the process of comparing the representational model with the selected modelling technique. Again, for the purpose of this paper we do not wish to formally specify the process of analysis and merely note that this work has been carried out, e.g., (Rosemann *et al.*, 2004; Gehlert and Esswein, 2007).

In general terms, representational analysis focuses on mapping relationships that are not 1:1. Such cases are classified as theoretical, i.e., potential, representational shortcomings. These undesirable situations can be further categorized into the following four types, as shown in Figure 1 (Weber, 1997):

- *construct overload* describes a situation in which a construct in the process modelling technique represents two or more representation model constructs (m:1 relationship),
- *construct redundancy* is the opposite case, i.e., one construct in the representation model is depicted by two or more constructs in the process modelling technique (1:m relationship),
- construct excess is the case in which at least one construct in the process modelling technique does not map to any construct in the representation model (0:1 relationship), and
- *construct deficit* describes the case in which at least one construct in the representation model does not map to any construct in the process modelling technique (1:0 relationship).

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Based on these four types of undesirable situation, it is possible to make predictions as to the representational capabilities of a process modelling technique for providing *complete* and *clear* representations of the domain being modelled (Weber, 1997). In particular, if a process modelling technique provides constructs for each element of the representation model, i.e., construct deficit is not present, it is regarded as *ontologically complete*. In turn, the *ontological clarity* of a process modelling technique can be measured by the degrees of construct overload, construct redundancy, and construct excess.

At this stage of the research progress, these representational issues are of theoretical nature. More explicitly, these theoretical findings denote *potential* issues for modelling users working with these process modelling techniques. Most of the related research is exclusively focused on this step within the research model. The identified potential issues, however, require further empirical testing. For this purpose they have to be transformed into propositions and testable hypotheses. As an example, a recent representational analysis (Recker *et al.*, 2006) identified construct deficit in the BPMN modelling technique with regards to representing aspects and concepts of states (e.g., stable states, state laws, conceivable state spaces, etc.). This deficit has led to the proposition that modellers using BPMN would have difficulty capturing the business rules of a given situation, as business rules demand rigorously specified state and transformation laws. Such a proposition can be converted into a testable hypothesis that in turn can be confirmed or falsified via empirical testing.

Empirically validating the theoretically identified representational issues requires access to sources of evidence. In most cases, this requirement will mean interviews and occasionally focus groups, or experiments, with business analysts or experienced students as proxies when access to practitioners is too difficult to organize. Surveys as a way of collecting related data are another option, but in reality researchers often struggle to identify the required number of participants for such a study. In our experience, predominantly semi-structured interviews have been used as an empirical research method in the process of representational analysis (Green and Rosemann, 2001; 2002; Davies *et al.*, 2004; Recker *et al.*, 2006).

The design of such interviews should follow a defined protocol that explores the significance of the identified issues. As Figure 2 indicates, five different levels of severity of an issue can be differentiated, with only level V representing a serious issue. Further follow-up questions would explore how the interview partner addresses this critical problem (e.g. free form annotations of the model, use of complementary techniques, etc.) and, in general, allow for extended reasoning and the exploration of further factors that may have remained invisible from the theoretical analysis.

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Gathered responses can be further codified based on collected demographic data. Further investigations into possible correlations will provide insights into the extent to which a perceived problem corresponds, for example, with years of experience in business process modelling. Previous research (Rosemann and Green, 2000; Davies *et al.*, 2004) has shown that besides the characteristics of the person who uses the process modelling technique (e.g., self-efficacy) the purpose of process modelling (e.g., for workflow engineering, Enterprise Systems implementation, compliance management) is a primary contextual factor with impact on the actual perceived criticality of the identified issue. The need for including these contextual factors in a representational analysis stems from the observation that different modelling objectives, purposes, cognitive abilities as well as other factors impact on the way process modelling technique users conceptualize their relevant real-world domain.

Overall, the subset of theoretical representational issues that is evaluated as critical in light of the empirical data becomes the set of empirically validated representational shortcomings and is further classified with contextual factors (e.g. person, purpose). The earlier stated proposition, for example, was confirmed using semi-structured interviews. In this particular case, 75 percent of interviewees that had a need to model business rules stated that they were unable to do so with BPMN. Follow-up questions further revealed that practitioners employed workarounds, such as narrative descriptions of business rules, spreadsheets, tables, and even UML state diagrams, in order to compensate for this deficit (Recker *et al.*, 2005; 2006).

Such identified and validated issues that stem from representational analysis form an important input for further revisions and improvements of existing process modelling techniques. In this phase, it is important to communicate the theoretical and empirical research outcomes back to the developers of the modelling technique or tool providers. The assumption of this type of research is that theoretically identified, empirically validated and communicated issues related to a process modelling technique have the potential to guide revisions of these techniques and ultimately lead to an increased quality of process models. The availability of improved models provides the involved stakeholders with better opportunities to achieve the goals underlying the process modelling initiative. From a research viewpoint, this is the phase in which methods for the evaluations of the quality of a process model can be utilized (e.g., based on the semiotic framework (Lindland *et al.*, 1994; Krogstie *et al.*, 2006)). Furthermore, improved model quality has to be placed in the context of the critical success factors of process modelling in order to have a realistic understanding of the impact of an improved modelling technique on the overall success of process modelling. In this context, the impact of the factor 'modelling language' to the overall success of process modelling initiatives was found to be significant (Bandara *et al.*, 2005; Bandara and Rosemann, 2005). Therefore, an improvement in the modelling technique will contribute ultimately to the success of the overall process modelling effort.

Figure 3 summarizes the phases of this type of research project.

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Figure 3 also shows how we have attempted to follow a Kuhnian approach to scientific method in our work. According to Kuhn (1962), scientific method is the process by which scientists, collectively and over time, endeavour to construct an accurate (that is, reliable, consistent and non-arbitrary) representation of real-world phenomena. Ultimately, the real-world phenomenon that we are interested in is the quality of model produced, in this case, the quality of the business process model produced. In other words, the ultimate dependent variable of interest to our work is quality of the model produced. The items through which we measure quality include, inter alia, level of completeness, ambiguity, and understandability. Our underlying assumption is that, if the modelling technique(s) used to produce the models is representationally incomplete, representationally ambiguous, and/or provides symbols that are not clearly understandable, then, *ceteris paribus*, the models produced using those techniques will suffer the same problems. Our theoretical foundation, the BWW models, informs us that a significant intervening variable potentially influencing our dependent variable is the representational capability of the modelling technique. We measure this intervening variable through the levels of representational completeness and clarity of a modelling technique. The levels of these measures are predicted through the representational analysis of the modelling technique and are then confirmed through empirical testing with users of that particular technique. We also realize that there are significant moderating variables that will impact the optimal level of representational capacity required in a modelling technique, *viz.*, the role of the person doing the modelling, and the purpose for which they are doing the modelling. Finally, suggestions to improve the modelling capacity of the technique can be made based on the empirically confirmed measures. Resultant business process models produced using the revised modelling technique can then be assessed in terms of their improved quality. Indeed, this aspect of the research program leads us to a very exciting phase whereby we hope to be able to test the improved business process model quality resulting from revisions to the modelling technique provided by the results of our evaluation of the representational capacity of the original modelling technique. In our work with the Business Process Modelling Notation (BPMN), for example, we have been in contact with the developers of that business process modelling technique and we have communicated with them regarding the results of our empirical testing of propositions resulting from our analysis of that technique. It will be a unique opportunity for testing improvements in business process model quality ultimately if we see future versions of BPMN reflecting the results of our original analytical work.

3 THE BWW REPRESENTATION MODEL & RELATED WORK

To fully appreciate the overall research model underlying representational analyses, it is necessary to gain an understanding of the underlying theory.

The development of the representation model that is known as the Bunge-Wand-Weber model emerged from the observation that, in their essence, Information Systems are representations of real world systems. Real world systems, in turn, can be explained and described using ontology - the study of the nature of the world and attempt to organize and describe what exists in reality, in terms of the properties of, the structure of, and the interactions between real-world things (Bunge, 1977, pp. 3-6; Shanks *et al.*, 2003).

Concerned that the lack of theoretical foundations underlying modelling method development would result in the development of Information Systems that were unable to completely capture important aspects of real world systems, Wand and Weber (1989; 1990b; 1993; 1995) developed and refined a set of models for the evaluation of modelling techniques and the scripts prepared using such techniques. The BWW representation model is one of three theoretical models defined by Wand and Weber (1995) that make up the BWW models. The application of the representation model to Information Systems foundations has been referred to by a number of researchers (Green and Rosemann, 2004) and the model is now often referred to as simply the BWW model. Some minor alterations have been performed over the years by Wand and Weber (1993; 1995) and Weber (1997), but the current key constructs of the BWW model can be grouped into the following clusters: things including properties and types of things; states assumed by things; events and transformations occurring on things; and systems structured around things (Green and Rosemann, 2005; Rosemann *et al.*, 2006). For a complete definition of the constructs refer to, for example, (Weber, 1997).

The BWW model has over the years reached a significant level of maturity, adoption and dissemination, and has been used in over thirty research projects for the evaluation of different modelling techniques, including data models (Wand and Weber, 1993), schema models (Weber and Zhang, 1996), object-oriented models (Opdahl and Henderson-Sellers, 2001; 2002) and reference models (Fettke and Loos, 2007). It also has a strong track record in the area of process modelling, with contributions coming from various researchers (Rosemann *et al.*, 2006). In this section, we briefly summarize those BWW related studies that focus specifically on process modelling techniques.

Keen and Lakos (1996) determined essential features for a process modelling scheme by evaluating six process modelling techniques in a historical sequence by using the BWW representation model. Among the modelling techniques evaluated were: ANSI flowcharts (American National Standards Institute, 1970), Data Flow Diagrams (DFD) (Gane and Sarson, 1979) and the IDEF Method 3 Process Description Capture Method (Mayer *et al.*, 1995) and the Language for Object-Oriented Petri nets (LOOPN++) (Keen and Lakos, 1994). The evaluation is restricted to the assessment of the ontological completeness of each technique and the authors did not empirically verify their findings on the features of process modelling schemes. From their analysis, Keen and Lakos concluded that, in general, the BWW representation model facilitates the interpretation and comparison of process modelling techniques. They propose the BWW constructs of system, system composition, system structure, system environment, transformation, and coupling to be essential process modelling technique requirements. However, we found that these findings are not entirely reflected in the leading process modelling techniques (Rosemann *et al.*, 2006).

Green and Rosemann (2000) analyzed the Event-driven Process Chain (EPC) notation (Keller *et al.*, 1992; Scheer, 2000) with the help of the BWW model, assessing both ontological completeness and clarity. Their findings have been empirically validated through interviews and surveys (Green and Rosemann, 2001; 2002; Davies *et al.*, 2004). Confirmed shortcomings were found in the EPC notation with regard to the representation of real world objects and business rules, and in the thorough demarcation of the analyzed process.

Green *et al.* (2005) examined the Electronic Business using eXtensible Markup Language Business Process Specification Schema (ebXML BPSS) v1.01 (OASIS, 2001) in terms of ontological completeness and clarity. While the empirical validation of results has not yet been performed, the analysis shows a relatively high degree of ontological completeness of ebXML.

Green *et al.* (2007) also compared different modelling standards for enterprise system interoperability, including Business Process Execution Language for Web Services v1.1 (BPEL4WS) (Andrews *et al.*, 2003), Business Process Modelling Language v1.0 (BPML) (Arkin, 2002), Web Service Choreography Interface v1.0 (WSCI) (Arkin *et al.*, 2002), and ebXML. These standards, which proclaim to allow for specification of intra- and inter-organizational business processes, have been analyzed in terms of their ontological completeness. The study found that ebXML provides a wider range of language constructs for specification requirements than other techniques, indicated through its comparatively high degree of ontological completeness. In addition, a minimal ontological overlap (MOO) analysis (Wand and Weber, 1995; Weber, 1997) was conducted in order to determine the set of modelling standards with a minimum number of overlapping constructs but with maximal ontological completeness (MOC), i.e., maximum expressiveness. The study identified two sets of standards that together allow for the most expressive power with the least overlap of constructs, *viz.*, ebXML and BPEL4WS, and, ebXML and WSCI. At the present point in time, this analysis too, has not yet been empirically validated.

Recker *et al.* (2005) used representational analysis to identify shortcomings in the Business Process Modeling Notation (BPMN) v1.0 (BPMI.org and OMG, 2006b) from the viewpoint of both clarity and completeness. Theoretical findings were tested with nineteen practitioners from six Australian organizations, resulting in the finding that there would appear to be representational shortcomings in BPMN, for example, in the modelling of business rules, and the usage of the Lane and Pool constructs (Recker *et al.*, 2006).

Recker and Indulska (2007) examined Petri nets (Petri, 1962) from the viewpoint of ontological completeness and clarity. The focus on Petri nets in their study stemmed from the observation that, while originally being a specification devoted to system dynamics, Petri nets have over time found adoption in regular process modelling communities, which in turn raises a need for evaluating their representational capacity. The study found that, surprisingly, the notation that consists of a mere seven constructs, provides a relatively high degree of ontological completeness. Deficits were for instance found in the support for the modelling of systems structured around things. The study also found that the same flexibility that affords Petri nets a higher ontological completeness, also results in extensive construct overload (for instance a place construct in a Petri net can be used to represent a thing, class, or state). The results from this analysis have not yet been tested with practitioners.

Overall, most of the conducted research has been of a purely theoretical nature. Most of the evaluations lack, at the time of writing, empirical verification of the theoretical findings. While this may in general be seen as problematic, the available theoretical studies nevertheless allow us to compare the results of these theoretical analyses over time in order to understand if process modelling techniques are actually improving in terms of their representational capabilities.

4 THE PROCESS MODELING DISCIPLINE – SIGNS OF MATURITY?

While representational analyses of process modelling techniques per se provide means for exploring strengths and weaknesses of these techniques, they can also be used as a means for assessing the evolution of technique development over time. As the process modelling discipline evolved only recently as a dedicated research field, we were curious whether this emerging research field would follow the overall guideline of establishing and building on a cumulative tradition (Keen, 1980). Our motivation then was to study the development of process modelling techniques over time, using representational capabilities as a measurement of increasing maturity.

We assessed the outcomes of twelve previous ontological analyses of process modelling techniques and put them in a historical sequence, starting with the analysis of Petri nets in its original and most basic form (Petri, 1962). Petri nets were chosen as we perceive it to be the intellectual birthplace of more rigorous and disciplined process modelling.

For comparison purposes the focus of this study was ontological completeness only. The notion of ontological completeness of a particular process modelling technique serves as an indication of its representational capabilities, being the extent to which the techniques are able to provide complete descriptions of a real-world domain. See (Recker *et al.*, 2009) for more details on this study.

The consolidation of the previous representational analyses leads to several interesting results. A longitudinal study of the ontological completeness shows an obvious increase in the coverage of BWW constructs. This finding can be interpreted as a sign of increasing representational development over time. Figure 4 visualizes this trend over time, as measured by the number of BWW constructs covered by each technique.

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We can see that, while the original Petri net specification did not provide exceptionally good representational coverage (41%) as defined by the BWW representation model, it still performed better than more recent techniques such as DFD (28%) or IDEF3 (38%). A noticeable spike in Figure 4 depicts the high level of development (in terms of ontological completeness) of the ebXML standard (76%). It is interesting to note that ebXML is specified in UML (OASIS, 2001), with a semi-formal construct definition and description, whereas BPEL4WS, WSCI, and BPMN, for example, have textual specifications supplemented by diagrams of examples. As such, the ebXML specification is less subjective in its possible interpretations. BPMN, too, appears to perform very well (66%) and hence appears to be quite mature in terms of representation capabilities. This higher level of ontological completeness can perhaps partly be explained by the fact that previous approaches, including EPC and Petri nets, influenced the development of BPMN (BPMI.org and OMG, 2006b).

It appears in general that techniques that focus on describing process flow from a business perspective (for instance DFD and IDEF3) are less ontologically complete than those that have to cater for more syntactical rigor due to their focus on executability or translatability into executable techniques (such as BPEL4WS or ebXML). However, the DFD and IDEF3 techniques were developed some time ago. Overall there is an upward trend in terms of the representational capability of the analyzed techniques. Indeed, it is clear that new techniques are building on the capabilities of the previous techniques. BPMN specifically has been designed by its authors with consideration of previous techniques and their advantages (BPMI.org and OMG, 2006b, p. 1).

5 REPRESENTATIONAL ANALYSES: FACTORS FOR CONSIDERATION

A representational analysis of process modelling techniques has two facets. On the one hand, it provides insights into potential issues with a modelling technique. On the other hand, it can also contribute to the further development of the selected theoretical model. In fact, our experiences with the application of the BWW models and our findings from the longitudinal analysis of process modelling techniques align with some of the previous criticisms of representational analyses (Rosemann *et al.*, 2004). In the following sub-sections, we discuss selected limitations and pitfalls of representational analyses and some approaches to avoiding them.

5.1 Relevance of the underlying representation model

The fact that even the most mature process modelling technique (ebXML) supports only 76% of the BWW constructs may perhaps suggest that the selected theory might be too demanding. Being an upper-level theory of representation, different application domains may induce a need for refining the set of constructs contained in the model to more relevant subtypes specific to the given domain. Regarding this potential lack of relevance of the BWW models, we suggest the development of a weighted scoring model that takes into consideration the specific needs of the BPM domain and assigns relative importance to constructs accordingly. All BWW-based analyses so far have been performed based on the assumption that representational capability for each of the BWW constructs is equally important. However, each domain might have different needs regarding the expressive power of modelling techniques, and therefore differing levels of importance for representation of various situations. For example, transformations are critical in the BPM domain, see also (Soffer and Wand, 2005), and by far outweigh the importance of being able to represent the history of state changes. For empirical evidence supporting this proposition please refer, for example, to (Recker *et al.*, 2006). Such differences should be recognized in the relative weighting of the BWW constructs for a given domain. With a developed and tested scoring model, it would then be possible to arrive at a final numeric score that measures the “goodness” of the analyzed technique or the significance of the identified issues. This score may then be easily compared with the scores of other notations, thereby providing an easy and objective way to choose a technique or notation that excels in areas of representation that are deemed important in a given domain.

The current BWW representation model also needs to be investigated in order to determine if there are constructs that may require further specialization. The need for such specialization has been noted by Weber (1997, p. 99) himself and has in some domains already been carried out, see, for instance, (Guizzardi, 2005, pp. 135 ff.).

For example, our empirical studies suggest that events and transformations occurring on things may require further specialization. BPMN, for example, distinguishes between nine event types, representing a differentiation scheme that is not covered by the BWW constructs of event and its subtypes. The same can be seen in standards such as ebXML, BPEL4WS, BPML, and WSCI. A similar situation holds for the transformation construct that we often found to be susceptible to construct redundancy. For example, in BPML there are ten language constructs representing different types of transformations. A similar situation exists in standards like BPEL4WS and ebXML. This situation implies that, just as ‘properties’ in the BWW representation model are specialized, perhaps transformations should be as well for the domain of BPM.

Also, it is interesting to note that throughout the analyses of process modelling techniques, control flow mechanisms such as logical connectors, selectors, gateways and the like are repeatedly regarded as construct excess as they do not map to any construct of the BWW representation model. However, these constructs are agreed to be essential to the BPM domain (for empirical evidence supporting this proposition refer to (Recker *et al.*, 2006)). While one might argue that an extension of the existing BWW model might be perceived as being required to deal with such issues in the BPM domain, this would contradict the sound philosophical nature of the theory. As such, extensions should be avoided and instead complementary analyses, e.g., using workflow patterns (van der Aalst *et al.*, 2003), should be conducted.

5.2 Subjectivity in the process of analysis

Another problem is related to the anecdotal criticism of the subjective nature of the analysis in which propositions are developed principally from the perceptions and experience of the researcher in the use of the BWW models in the analysis. This concern is conceded also by Weber (1997, p. 94) who contends “that two individuals might look at the same grammar and “see” two different sets of grammatical constructs”. Moreover, “one person’s perception of a mapping between an ontological construct and a grammatical construct might not be the same as another person’s perception” (Weber, 1997, p. 94).

Accordingly, the representation mapping step should be conducted in multiple iterations between various researchers. In a first step, the mapping should be performed by each involved researcher. The researchers should then meet to discuss and defend their respective mappings, leading to a second joint mapping draft. This joint draft should then be presented, discussed and defended in front of the complete research team or even experts in the field of representational analyses, thereby leading to a final, agreed draft. In previous studies, we were able to increase the extent of agreed mappings, i.e., construct mappings that are agreed upon by every involved researcher, over three iterations. This process in turn served as an indication of the objectivity of the mapping results. While our previous studies have used a percentage agreement calculation, Cohen's Kappa (Cohen, 1960) should be used in order to measure the level of agreement in research teams that consist of multiple individual coders.

Subjectivity in such analyses can further be reduced with the use of meta-models. If a meta-model exists for the chosen representation model, and if the target technique or notation is specified in the same language as the meta-model, then it is possible to perform a more objective assessment that is based on pattern matching between the meta-models of the representation model and the technique. As previously stated, an EER (Extended Entity Relationship model) based meta-model for the BWW representation model has already been developed (Rosemann and Green, 2002). This model can be used to more easily and objectively analyze techniques and notations specified in EER or ER. There is a need to translate this model into UML, as this notation tends to be the standard used in specifications currently. There is also a need for the authors of techniques and notations to realize the importance of a more formal specification, rather than a text-based one. While ebXML, for example, has a semi-formal, UML-based specification (OASIS, 2001), and could therefore be more objectively analyzed with a UML-based BWW meta-model, many other notations (e.g., BPMN) are informally specified. The need for meta-model-based specification, however, is increasingly recognized by technique developers. The BPMN development team, for example, is currently working on a UML-based meta-model (BPMI.org and OMG, 2006a).

5.3 Multi-level analysis of modelling capabilities

The majority of representational analyses of modelling techniques is based on the (textual, semi-formal or formal) specification of the modelling technique, e.g., in form of a meta-model. The actual application of a modelling technique, however, has to be also seen from the viewpoint of the supporting modelling tool and the company's individual modelling conventions. Thus, potentially, three levels for a representational analysis can be differentiated:

a) the (classical) level of the modelling technique
b) the way a certain modelling tool supports a modelling technique
c) the company-specific way in which a tool-supported technique is constrained by internal conventions.

The current focus on the first level of analysis provides important insights into potential and actual issues with a modelling technique. However, we have found that many of these issues are overcome by a modelling tool that might address these issues (Recker *et al.*, 2006). For example, some process modelling techniques do not provide constructs for decomposing or structuring the modelled system or process. While this denotes a theoretical representational shortcoming, we have found that in practice it is not perceived as such due to complementary tool support, for example, by means of storing and linking inter-related process models in a repository. Individual modelling conventions provide another opportunity to address potential sources of ambiguity. An example of this is the use of colour-coding schemes to differentiate language constructs (e.g., coloured activity symbols to differentiate automated from manual tasks) in order to overcome the theoretical shortcoming of construct overload.

Thus, a representational analysis that only focuses on the level of a generally specified modelling technique does not consider these two additional levels, which are relevant in the practical application of process modelling.

5.4 Terminology employed in theory and practice

Empirical testing of representational analyses can in some cases be problematic due to the differences in terminology used by researchers and BPM practitioners. The terminology of the BWW models is concerned with abstract and formal specifications of high-level constructs that may not be easily, or correctly, understood without prior exposure to the model and its specification. The design of complementary empirical research strategies that seek to test theoretical propositions thus has to take into account the problem of translating the terminology of the BWW models to the appropriate domain and the users within. As an example, our representational analysis of BPMN revealed a lack of constructs for representing concepts such as conceivable state spaces and lawful event spaces. When developing an accordant interview protocol for testing the propositions derived from these findings, we had to place emphasis on communicating and explaining the detected deficiencies in a terminology close to the one used by modelling practitioners instead of asking users, for example, "Can you model conceivable state spaces?"

5.5 The true nature of a 1:1 relationship

As outlined in earlier sections, the idea of a representational analysis is based on the assumption that any relationship between corresponding constructs of the representational benchmark and the selected modelling technique, which is not a 1:1 relationship, leads to potential ambiguity or incompleteness. However, the notion of a 1:1 relationship is not precise and the notion of the entirety of one construct requires further specification. Instead of asking, "Is there a symbol in the modelling technique, which supports a representational construct?" a more detailed study could explore the nature of the representational construct. For example, just because the BWW construct thing is supported in the Event-driven Process Chain by an "Organizational Unit" (Green and Rosemann, 2000) does not mean that the EPC is in this regard ontologically complete. Instead, it is necessary to identify all relevant facets of a thing, and then it becomes obvious that an EPC cannot model, for example, individual instances of documents which are transformed within a process. In fact, the construct "Organizational Unit" represents a subtype of a thing, more specifically an indirect subtype that specializes the notion of Agentive Physical Entity (Masolo *et al.*, 2003). As a consequence, there is a need not only to further empirically test the actual significance of the non-1:1-relationships, but at the same time evaluate if a 1:1 relationship truly represents a "corresponds with" relationship or if it is maybe more a "is-a" relationship, which supports only one specialization of the construct. This latter case again hints at a potential need to specialize certain constructs in the underlying representation model.

5.6 Involving designers of the modelling technique

Only a limited number of research projects that evaluated the representational capabilities of modelling techniques, has applied empirical analysis in order to verify the identified issues. In these few cases, either business analysts, e.g., (Davies *et al.*, 2004; Recker *et al.*, 2006), or experienced coursework students, e.g., (Green and Rosemann, 2001), have been used.

What so far has been missing in all considered representational analyses is the discussion of the confirmed analysis findings with the designers of the respective modelling technique. In fact, it is a general trend in IS research that assessment usually stops as soon as weaknesses in the theory or the developed artefact have been identified. Hevner *et al.* (2004, p. 80) note hereto that "the refinement and reassessment process is typically described in future research directions." However, what good can findings from extensive evaluation strategies do if they are not incorporated in the re-design, extension or improvement of the evaluated artefact? In order to counteract this limitation we sought to involve the designers of the BPMN modelling technique in our study of its representational capabilities and conducted telephone interviews with the development team in which we advised them and discussed with them the identified representational issues. The main aim of these communications was to focus on how future revisions of the technique specification may overcome the identified representational shortcomings (see also the second last step in the research model in Figure 3).

6 CONTRIBUTIONS & CONCLUSIONS

This paper discussed the use of an ontology-based theory of representation for the study of process modelling techniques. We gave insights into the process of representational analyses, explored some related perils and pitfalls and also showed benefits that can be obtained from these studies. For example, we discussed how the outcomes of representational analyses can be of interest to the developers and users of process modelling techniques. Developers of process modelling techniques should be motivated to examine representational analyses of currently used process modelling techniques in order to build upon these and counteract any weaknesses in newly developed techniques or technique extensions. On the other hand, users of process modelling techniques might be motivated to use ontological completeness and clarity as potential evaluation criteria for the selection of a most appropriate modelling technique.

We also presented a longitudinal study of representational analyses of process modelling techniques based on the review of previous studies in the field. The findings clearly show signs of a maturing modelling discipline, as measured by an increased ontological completeness of process modelling techniques over time. The results also identify the common core constructs of process modelling techniques (for example, transformation, properties, events) as well as their key differentiators (for example, subsystem, system environment, lawful state space). Furthermore, the findings provide valuable insights for the future application of the BWW model as a benchmark for such analyses of modelling techniques. We hope that such research might also motivate other researchers to conduct a similar study for data or object-oriented modelling techniques.

Forthcoming from the review of related studies and our own experiences, we foresee significant opportunities for further research in the area of representational analysis of process modelling techniques. Accordingly, in the conclusion of this paper we would like to share some thoughts on future research challenges in this area.

There is evidence, based on our experience, that there is a need for a specialization of certain constructs of the BWW model and for the development of a weighted scoring model for the domain of BPM. While the BWW model can be seen as one way of conceptualizing the things and systems in the world (and the interactions between those things) that are relevant to Information System domains, a question remains whether the BPM domain itself has a need to do the same. In our analyses we have found that there are some constructs of the BWW model that are supported by only one technique of the chosen twelve, for example the BWW constructs kind and history. While this might indicate an area of improvement of the representation power of process modelling techniques, it might also indicate that, perhaps, the particular BWW construct is not necessary for modelling in the domain of BPM. Such issues require further empirical testing in order to determine whether the constructs are indeed required. Based on such further testing, it will be possible to develop a weighted scoring model that assigns higher weights to the critical constructs, lower weights to constructs that are not detrimental to modelling business processes, and zero weights to constructs that are not deemed to be necessary for the BPM domain. At the same time, the BWW model should be further studied in light of the empirical testing, to determine whether there is a need to specialize any constructs into more differentiated sub-types (e.g., transformation as our study would indicate).

Furthermore, we also see strong benefit in performing a study of ontological clarity of process modelling techniques over time, as a complement to ontological completeness. This should be followed by experiments that aim to assess the impact of completeness and clarity on the intuitiveness of the model, similar to (Gemino and Wand, 2003; 2005), and a study of the impact of representational capabilities on the uptake and acceptance of process modelling techniques in modelling initiatives (Recker, 2008). We anticipate that these types of study will contribute to developing a comprehensive understanding of the quality of a process model produced, incorporating syntactical (for example, consistency of the language meta-model), semantic (for example, representational shortcomings in a technique) and pragmatic aspects (for example, the impact of ontological clarity on the perceived intuitiveness of the model produced).

As a concluding remark we would like to add that we have found the research method of representational analysis very fruitful in understanding and exploring the challenges of process modelling and we expect this type of research to continue to give stimulating input to both academic and practical work in the area of process modelling in the future.

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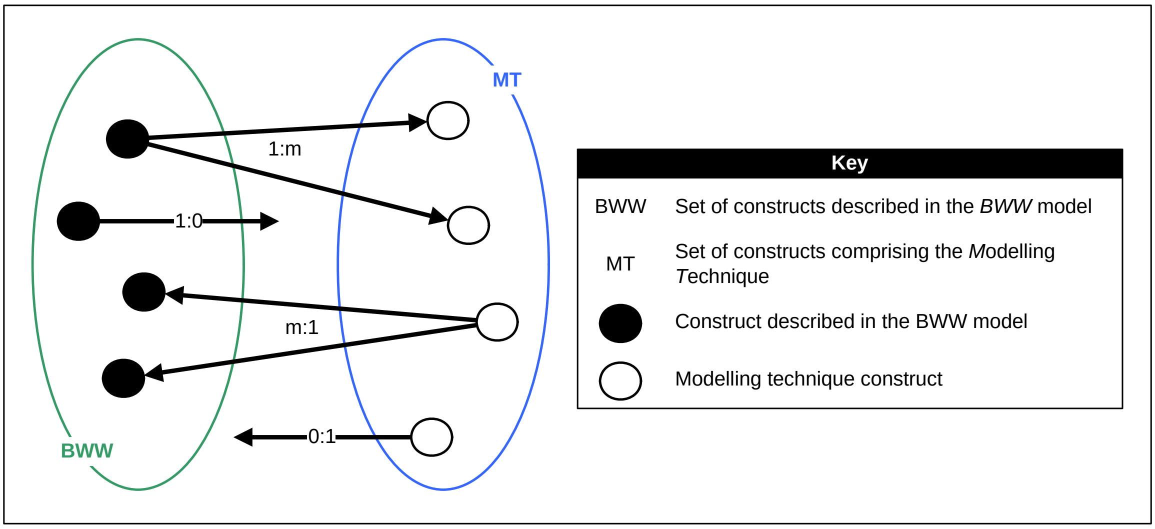

Figure 1 *Types of potential representational shortcomings*

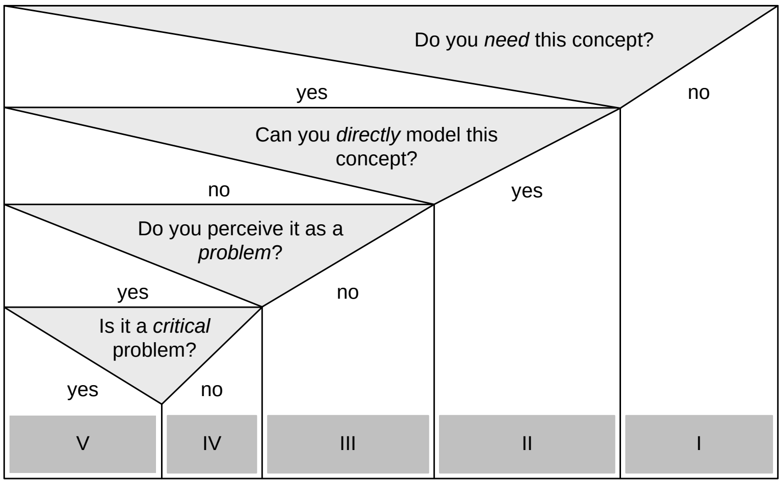

Figure 2 *Questionnaire structure and response classification*

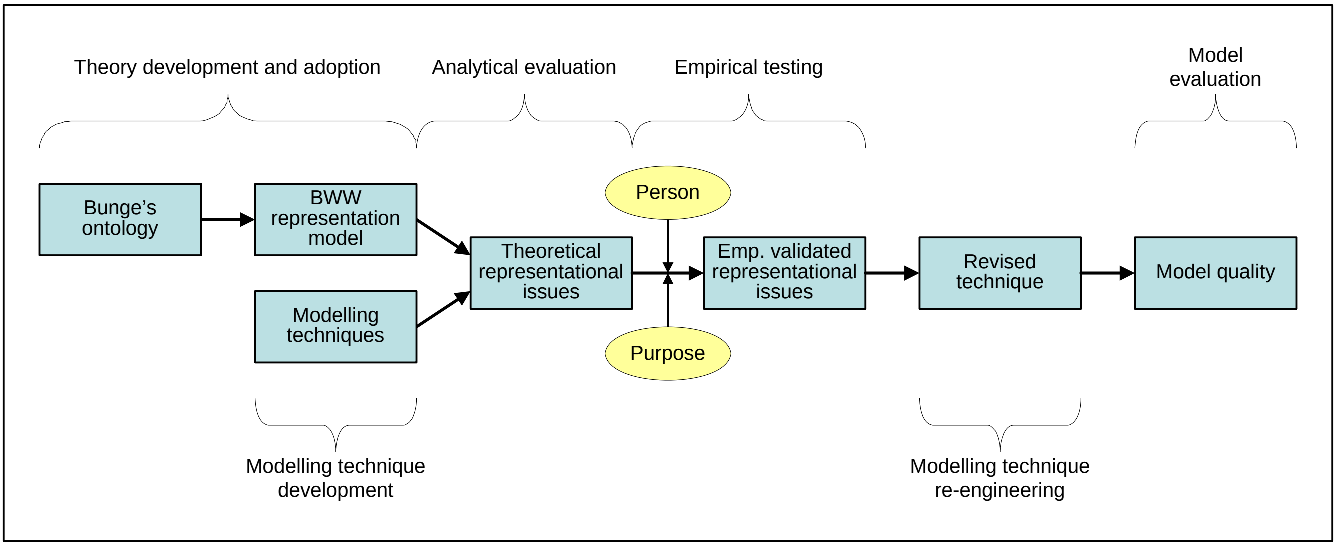

Figure 3 *The main phases of representational analysis of modelling techniques*

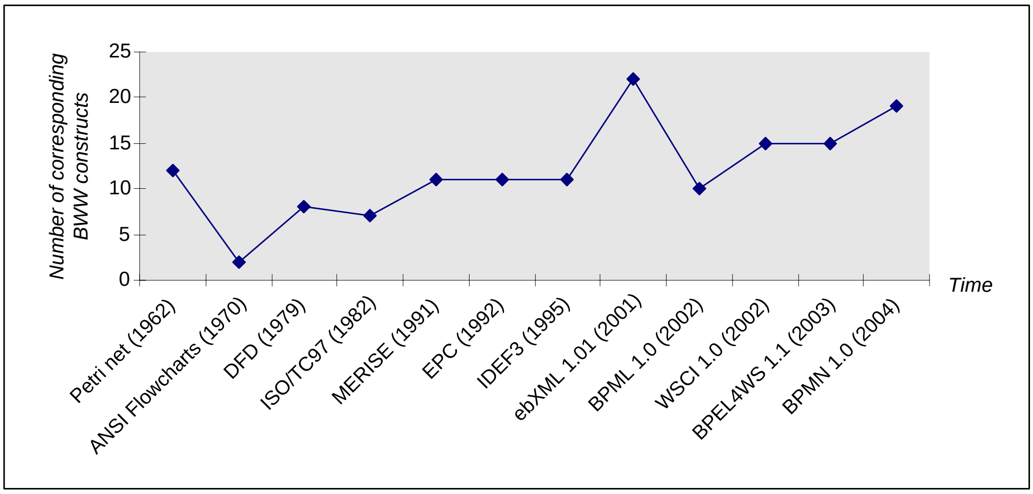

Figure 4 *Comparison of representation mapping analyses*