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DO ONTOLOGICAL DEFICIENCIES IN MODELING GRAMMARS MATTER?[1]

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Conceptual modeling grammars are a fundamental means for specifying information systems requirements. However, the actual usage of these grammars is only poorly understood. In particular, little is known about how properties of these grammars inform usage beliefs such as usefulness and ease of use. In this paper, we use an ontological theory to describe conceptual modeling grammars in terms of their ontological deficiencies, and formulate two propositions in regard to how these ontological deficiencies influence primary usage beliefs. Using BPMN as an example modeling grammar, we surveyed 528 modeling practitioners to test the theorized relationships. Our results show that users of conceptual modeling grammars perceive ontological deficiencies to exist, and that these deficiency perceptions are negatively associated with usefulness and ease of use of these grammars. With our research, we provide empirical evidence in support of the predictions of the ontological theory of modeling grammar expressiveness, and we identify previously unexplored links between conceptual modeling grammars and grammar usage beliefs. This work implies for practice a much closer coupling of the act of (re-)designing modeling grammars with usage-related success metrics.

Keywords: Conceptual modeling, perception measurement, usage behavior, ontology

Introduction

A major task undertaken by information systems analysts and designers is to document the common understanding that stakeholders have about a real-world domain intended to be supported by an information system. This documentation is often in the form of conceptual models (Maes and Poels 2007). These models are constructed using a modeling *method* (a procedure for constructing models), and a modeling *grammar*, which consists of a set of graphical constructs and rules to combine those constructs (Wand and Weber 2002).

Conceptual modeling is an active research area in Information Systems (Burton-Jones et al. 2009). In particular, a considerable amount of work has examined the role of conceptual modeling grammars in building or interpreting high-quality models (Siau and Rossi 2010). In this vein of research, scholars have increasingly drawn upon theoretical work based on the concept of ontology to design and evaluate modeling grammars and conceptual models. Specifically, work by Wand and Weber (1990, 1993) toward a theory of ontological expressiveness of conceptual modeling grammars has received much attention over recent years (e.g., Bowen et al. 2009; Burton-Jones and Meso 2006; Shanks et al. 2008). Related research has examined, *inter alia*, how conceptual

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modeling grammars are capable of creating models that provide a faithful representation of some real-world domain (e.g., Recker et al. 2009), or how a specific conceptual model provides a faithful representation of a real-world domain (e.g., Burton-Jones and Meso 2006).

While prior work based on Wand and Weber's (1990, 1993) theory of ontological expressiveness has examined characteristics of modeling grammars, or characteristics of models created with such grammars, our research is interested in examining how the theory of ontological expressiveness informs an understanding of the usage of conceptual modeling grammars. Specifically, we seek to examine whether, and how, this theory informs usage beliefs of the users working with modeling grammars to create conceptual models. This area of research is important because the decision of the type of grammar to be used for conceptual modeling defines the world view that can be taken and it specifies the limits of what can be modeled (Hirschheim et al. 1995). Informing an understanding of how ontological characteristics of modeling grammars are associated with usage beliefs about the grammar is also critical in developing an informed opinion about the long-term viability and success of a modeling grammar.

This paper brings the stream of research on ontological expressiveness one step closer to practice. By building a link between ontological properties of a grammar and related perceptions of users of this grammar, it goes beyond the common identification and validation of ontological deficiencies in grammars (e.g., Green and Rosemann 2001). The outcomes quantify for the first time the impact of these deficiencies on the usage beliefs of practitioners. Thus, it allows informed statements about the actual impact and importance of such research and its relevance for practice.

In this paper, we describe research we undertook to study whether properties of a conceptual modeling grammar inform two key perceptual beliefs associated with the usage of the grammar, *viz.*, perceived usefulness and perceived ease of use. We use a theory of ontological expressiveness (Wand and Weber 1993) to facilitate an understanding of four key properties of conceptual modeling grammars in terms of their levels of ontological completeness and ontological clarity. We use this theory to analyze the ontological deficiencies of one of the most popular grammars for process-oriented conceptual modeling, the Business Process Modeling Notation (BPMN; BPMI.org 2006). We then examine empirically whether the ontological deficiencies of BPMN (as predicted through the selected theoretical base) manifest in the perceptions of the users of the grammar. Subsequently, we examine whether the perceptions of these deficiencies inform user perceptions about the usefulness and ease of use of the grammar. The research question we seek to answer in this study is

> **How are users' perceptions of ontological deficiencies that exist in a modeling grammar associated with their beliefs about the usefulness and ease of use of the grammar?**

Theory

The type of grammar used for conceptual modeling defines the language and its grammatical rules, which can be used to articulate and communicate a real-world domain, and thus determines outcomes of the modeling process. There is a need, consequently, to understand the modeling capabilities, and limits thereof, of a modeling grammar, and the implications these limits have on the actual usage of the grammar. This understanding is of equal importance for the developers of modeling grammars as well as for their end users.

We turn to a theory of ontological expressiveness (Wand and Weber 1993) to facilitate this understanding. The theory was developed from the adaptation of an ontology proposed by Bunge (1977). It suggests an ontological model of representation, which specifies a set of rigorously defined ontological constructs to describe all types of real-world phenomena that a modeling grammar user may desire to have represented in a conceptual model of an information systems domain.

Wand and Weber's (1993) theory purports to account for variations in the ability of conceptual modelers to develop models of real-world phenomena that are ontologically *complete* and *clear*. To do so, it considers the nature of the mapping between representations and real-world phenomena. Wand and Weber (1993) argue that, for a grammar to be ontologically expressive, the mappings between constructs in a modeling grammar to constructs in the ontological model should be isomorphic. Based on this argument, the theory identifies four types of *ontological deficiencies* of a modeling grammar stemming from a lack of isomorphism in the mapping of modeling grammar constructs to constructs in the selected ontological model.

1. Construct deficit: An ontological construct exists that has no mapping from any modeling construct (a 1:0 mapping).

2. Construct redundancy: Two or more modeling constructs map to a single ontological construct (a 1:m mapping).

3. Construct overload: A single modeling construct maps to two or more ontological constructs (a m:1 mapping).

4. Construct excess: A modeling construct does not map onto any ontological construct (a 0:1 mapping).

Proposition Development

Wand and Weber's (1993) theory of ontological expressiveness argues that lack of ontological completeness and lack of ontological clarity undermine a user's ability to use a modeling grammar for creating models that contain representations of all required real-world phenomena.

Several researchers have empirically tested this argument. Recker et al. (2010), for instance, found that construct deficit motivated grammar users to employ additional means to help articulate the real-world phenomena they felt could not be expressed with the grammar in use. Bodart et al. (2001) and Gemino and Wand (2005) showed how the existence of construct excess in a conceptual model resulted in users misunderstanding the model. Similarly, Shanks et al. (2008) demonstrated that construct overload undermined users' ability to understand the information contained in the model.

Our contention is that ontological deficiencies of a modeling grammar will also be associated with key beliefs individuals develop about the usage of these grammars when creating conceptual models. Our arguments rest on the assumption that modelers would have lower perceptions of grammars that do not exhibit adequate levels of completeness and clarity. After all, they would not be able to capture all of the phenomena they require to articulate in their models.

Prima facie, ontologically complete and clear grammars are preferable. However, whether or not ontological deficiencies of a modeling grammar indeed imply a practical or observable disadvantage, or are perceived as an issue by the users working with the grammar, is an empirical question (Gemino and Wand 2005). For instance, assume that a grammar exhibits construct deficit pertaining to the articulation of business rules. If a user working with the grammar does not perceive a need for capturing business rules or does not perceive a problem in describing business rules using the grammar, his or her evaluation of the grammar would not be negatively affected by the missing capability.

Therefore, we speculate that beliefs about a behavior with regard to an object (in this case, perceptions about the use of a grammar for modeling purposes) will be associated with beliefs about the object itself (in this case, perceptions of grammar deficiencies). Consider the case that the modeler perceives the need to articulate business rules in a conceptual model and finds himself/herself unable to do so because of the deficit of constructs required to graphically articulate business rules. Then, he/she is likely to have a decreased belief about the usefulness of the grammar for his/her modeling tasks.

This argumentation builds upon the reasoning of Downs and Mohr (1976). They argue that secondary qualities of an object (i.e., an individual's perceptions of its primary qualities) determine the formation of beliefs toward behavior associated with the object. Consider the case of a product that is annotated with a certain price. A purchase decision will not be made on the basis of the actual (i.e., primary) price attribute (an attribute of the object) but rather on whether an individual perceives the price to be reasonable or expensive (i.e., the secondary attribute—a belief about the object). We argue that the same situation holds for modeling grammars.

While perceptions about the usage of a modeling grammar are largely unexplored, there is some evidence to suggest that two behavioral beliefs specifically, *perceived usefulness* and *perceived ease of use*, are key to understanding modeling grammar usage beliefs. Davies et al. (2006) report that perceived usefulness and perceived ease of use (measured as complexity) are the two most frequently reported factors influencing the decision to continue using conceptual modeling in practice. Also, Recker (2010a) shows that perceived usefulness and perceived ease of use are the two strongest drivers influencing intentions to continue using a process modeling grammar. Both studies highlight the relevance of the two beliefs to the formation of usage beliefs, and justify our interest in these constructs in this study. Therefore, we suggest two propositions that we seek to test in this paper.

First, we theorize a negative association between the perception of a lack of ontological completeness in a grammar (a belief about the grammar) and its perceived usefulness (a belief about a behavior with regard to the grammar). Following Davis (1989), perceived usefulness can be understood as the degree to which a person believes that a particular grammar is effective in achieving the intended modeling objective. Gemino and Wand (2004) argue that completeness is one measure for the effectiveness of a grammar. Ontologically, a complete grammar would be one without construct deficit. Therefore, if users cannot build representations of all required phenomena because they perceive manifestations of deficits of desired representation constructs in a grammar, they are likely not to find the grammar useful. This reasoning leads to the first proposition.

P1. *Users' perceptions of a conceptual modeling grammar's lack of ontological completeness will be negatively associated with their perceived usefulness of the grammar.*

Second, we theorize a negative association between the perception of a lack of ontological clarity in a grammar (a belief about the grammar) and its perceived ease of use (a belief about a behavior with regard to the grammar). Following Davis (1989), perceived ease of use captures beliefs about the effort that is needed to apply a grammar. Wand and Weber (1993) argue that the ontological clarity of a grammar indicates how unambiguously the meaning of its constructs is specified and, thus, how much effort is needed to apply desired real-world meaning to the constructs. The argument is that a certain grammar may well be complete (and hence potentially useful) in that it provides all constructs necessary to build representations of all desired real-world phenomena, but some of these constructs may be *redundant* in that one ontological meaning can apply to different grammatical constructs, *excessive* in that they do not provide any required real-world meaning, or *overloaded* in that they carry multiple ontological meanings. Overall, the use of the grammar may, therefore, be perceived as causing confusion and/or ambiguity, which adds complexity to the modeling task. We argue, accordingly, that *perceptions of a lack of ontological clarity* are negatively associated with the perceived ease with which a grammar is used. This situation manifests because construct overload, redundancy, and excess of a grammar pose limitations on the way a grammar is used for modeling because they affect *how* phenomena can be articulated. Consider the case of two grammars that share the same degree of completeness but exhibit different levels of ontological clarity. Intuitively, a modeler would choose the grammar that he/she perceives to require the least effort to use for the articulation of the phenomena he/she requires to describe. This reasoning leads to our second proposition.

P2. *Users' perceptions of a conceptual modeling grammar's lack of ontological clarity will be negatively associated with their perceived ease of use of the grammar.*

One might argue that perception of a lack of clarity may also affect perceptions about the usefulness of the grammar. For instance, if a grammar has construct overload, the models created using the grammar will be ambiguous and, therefore, less useful for the task of facilitating intuitive communication across stakeholders (Shanks et al. 2008). Yet, while model interpretation occurs also during model creation stages (for instance, when a developer reads an earlier draft of a model in order to create a revised model draft), we argue that a grammar is useful for model creation first and foremost if it is expressive (i.e., if it allows the user to depict all real-world phenomena he/she chooses to have represented in a conceptual model). Expressiveness, consequently, is dependent on the availability of sufficient representation constructs in the grammar. A lack of clarity of these constructs, however, does not affect the expressiveness of a modeling grammar. Instead, ontological clarity concerns the question whether the grammar permits a clear and unambiguous interpretation of its constructs during model creation, which manifests in the ease of using a grammar.

Nevertheless, ease of use beliefs will have an influence on the perceptions about the usefulness of a modeling grammar because ease of use suggests that users of a modeling grammar may achieve performance gains faster (Recker 2010a). A clear interpretation of the grammar constructs will allow a user to select in an effortless manner appropriate constructs to express all required phenomena. This affordance, in turn, may lead to an increased perception of the usefulness of the grammar. Figure 1, which visualizes the two propositions of our study, depicts the suggested relationships between ontological grammar characteristics and perceived ease of use and perceived usefulness of a grammar.

Figure 1 foreshadows our ensuing analysis. Specifically, it shows that, to draw conclusions about proposition P1, we will measure the extent to which users of the BPMN process modeling grammar perceive three manifestations of construct deficit (PCD1–PCD3) to exist in the grammar, and the extent to which these perceptions inform beliefs about the usefulness of the grammar. Similarly we identified three manifestations of construct redundancy (PCR1–PCR3), two manifestations of construct overload (PCO1–PCO2), and four manifestations of construct excess (PCE1–PCE4), to be able to draw conclusions about proposition P2—the impact of perceptions of lack of grammar clarity on perceptions of ease of use of the grammar. We detail this analysis, and the results thereof, in the following sections.

Research Method

Data Collection

We collected empirical data via a field survey of users of a particular conceptual modeling grammar, BPMN, during four months in 2007. The survey method is appropriate when clearly identified independent and dependent variables exist, and a specific model is present that theorizes the relationships between the variables (Pinsonneault and Kraemer 1993), which is the case in our study.

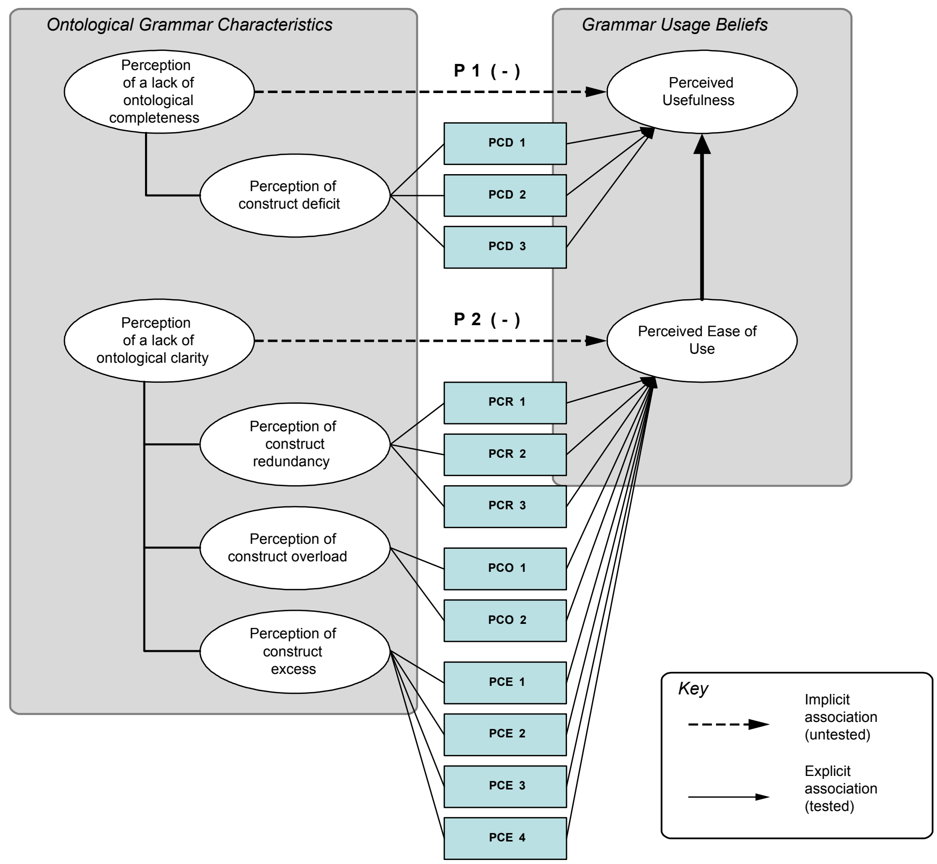

Figure 1. Research Model

We selected BPMN as the modeling grammar of choice for several reasons. BPMN is an important modeling standard in the design of process-oriented software systems (Ouyang et al. 2009), web services (Decker et al. 2009), and service-oriented architectures (Rabhi et al. 2007). It has significant uptake in the community of system, business, and process analysts, and it is used for typical IS application areas such as business analysis, workflow specification, requirements analysis and systems configuration (Recker 2010b). The choice of a single grammar as a reference for data collection was necessary in this study to be able to examine, at the desired micro-level, the effects of certain types of ontological grammar deficiencies on individual usage beliefs. It also allowed us to control for the potential effects of macro-level variables (e.g., modeling infrastructural constraints, modeling method variations, and others).

Data was collected globally from BPMN grammar users via a web-based instrument. Web-based surveys are advantageous over paper-based surveys in several ways (e.g., lower costs, no geographical restrictions, faster responses). Users were invited to participate in the online survey through advertisements made in online forums and blogs (e.g., www.bpm-research.com, www.brsilver.com/wordpress/, www.Column2.com), through modeling tool vendor announcements (e.g., itp-Commerce, IDS Scheer, Casewise, Tibco, Intalio), and through practitioner magazines and communities (e.g., BPTrends.com, ABPMP, BPM-Netzwerk). Participants were informed about the type and nature of the study and they were offered incentives for participation, specifically, a summary of the results, the opportunity to attend a free modeling seminar, and the chance to win a free textbook. Appendix A provides a copy of the survey instrument.

We received 590 responses in total, of which 60 were incomplete and two invalid. After eliminating these entries, we obtained a sample of 528 usable responses. The respondent group ranged in organizational and personal demographics (see Table 1).

Table 1. Participant Demographic Data			
Aspect	**Values**	**Frequency**	**Percentage**
Organizational demographics			
Type	Public sector	186	35.23
	Private sector	342	64.77
Size	Less than 100	157	29.73
	Between 100 and 1000	134	25.38
	Over 1000	237	44.89
Size of modeling team	Less than 10	379	71.78
	Between 10 and 50	127	24.05
	Over 50	22	4.17
Personal demographics			
Continent of origin	Africa	14	2.65
	Asia	36	6.82
	Europe	174	32.95
	North America	133	25.19
	Oceania	131	24.81
	South America	40	7.58
Type of training	Formal/certified BPMN course	56	10.61
	Internal/in-house BPMN course	30	5.68
	University BPMN course	24	4.55
	On the job training	77	14.58
	Self-taught	211	39.96
	Read the specification	116	21.97
	Other	14	2.65
Years of experience in modeling overall	Less than 2 years experience	159	30.11
	Between 2 and 5 years experience	164	31.06
	Between 5 and 10 years experience	115	21.78
	Over 10 years experience	90	17.05
Months of experience in modeling with BPMN	Less than 6 months experience	294	55.68
	Between 6 and 12 months experience	132	25.00
	Between 12 and 24 months experience	62	11.74
	Over 24 months experience	40	7.58
Number of BPMN models created	Less than 10 models created	170	32.20
	Between 10 and 25 models created	167	31.63
	Between 25 and 50 models created	99	18.75
	Over 50 models created	92	17.42

From the perspective of modeler experience, our respondents fall into four roughly equal-sized clusters: those with very little experience, those with some experience, those with substantial experience, and those with extensive experience. While this distribution of respondents matches other surveys of conceptual modelers (e.g., Davies et al. 2006), respondents' experience in BPMN modeling ranged from 15 days to 5 years (with an average of 9 months and a median of 4 months), whereas Davies et al. (2006) report average experience in modeling to be 6.4 years (with a median of 5). The limited amount of BPMN experience is likely due to its relatively recent release as an OMG standard. While BPMN has been available in version 0.9 since 2002, ratification as a standard was triggered in 2006 and finalized only in 2007.

Before administering the field study, we ran a pre-test and a pilot test. In the pretest four academics with knowledge of the study were asked to complete a paper-based version of the survey instrument in face-to-face meetings. During survey completion, notes were taken based on comments received. After instrument revision, the measurement instrument was pilot-tested with a sample of 41 graduate students with knowledge of the target grammar. After exploratory factor analysis, changes were made to the measurement instrument and to those scales that indicated problems in meeting required psychometric properties.

Design and Measures

Six constructs were measured in this study: perceived usefulness (PU), perceived ease of use (PEOU), perceived construct deficit (PCD), perceived construct redundancy (PCR), perceived construct overload (PCO), and perceived construct excess (PCE). All constructs were measured using multiple-item scales, using seven-point Likert scales anchored between "strongly agree" (coded as 1) and "strongly disagree" (coded as 7). Appendix A provides operational definitions and sources for all constructs (see Table A1) and it displays the final survey instrument with all scale items (see Appendix A, "Survey Instrument").

Perceptual Measures of Modeling Grammar Usage

Scales for the constructs PU and PEOU were drawn from pre-validated measures in IS usage and acceptance research (Davis 1989; Moore and Benbasat 1991), and were reworded to relate specifically to the context of BPMN grammar use. We used a procedure similar to that reported by Moore and Benbasat (1991) for the adaptation of the original scales to the conceptual modeling domain. Specifically, the perceived usefulness construct was measured using three items adopted from Moody's (2003) adaptation of Davis' (1989) original scale. One item (PU1) taps into an overall judgment of usefulness while the remaining two items assess usefulness (in the sense of effectiveness) in explicit relation to the domain substrata conceptual modeling purpose (PU2) and objective (PU3).

The perceived ease of use construct was measured using three items adopted from Davis' original scale. The three selected items include one item to measure the effort of applying a conceptual modeling grammar for a specific conceptual modeling purpose (PEOU1), one item to measure the effort of learning how to apply a conceptual modeling grammar (PEOU2), and one item to measure the effort of performing conceptual modeling tasks with the grammar, that is, the effort of building conceptual models (PEOU3).

Perceptual Measures of Modeling Grammar Deficiencies

To measure perceptions of construct deficit, redundancy, overload, and excess, we needed to find a way to identify the extent to which these deficiencies existed in the grammar under observation. The challenge was to devise a measurement of how users working with BPMN would perceive the deficiencies that, *prima facie,* exist within the BPMN grammar as per Wand and Weber's (1993) theory, without the users being required to be aware of the theory.

We operationalized and measured each manifestation of an ontological deficiency separately. We decided to do so for four main reasons. First, this step allowed examination of the actual features of the grammar (i.e., the nature and type of its graphical representation constructs). Second, in our study, we tested the premises of Wand and Weber's theory of ontological expressiveness, which allows speculation about the nature, and implications, of the representation constructs contained within a modeling grammar. Consequently, we sought measurements that operate on the same level as the original theory propositions. Third, our approach allowed us to use modeling situations with specific wording (e.g., "The BPMN modeling grammar does not provide sufficient symbols to represent business rules in process models"). In turn, the final items are more understandable to end-users. Fourth, the research findings lead to more specific insights into the nature of a modeling grammar rather than to outcomes that relate to the modeling grammar as a whole.

Accordingly, we developed new scales to measure user perceptions about the various manifestations of construct deficit, redundancy, overload, and excess existent in the target grammar used in our study. As a basis for developing these scales, we identified the existence, and type, of ontological deficiencies associated with the BPMN grammar. This process is known as ontological analysis (Wand and Weber 1993). We followed an extended methodology for our analysis (Green and Rosemann 2005). We report the details of the analysis in Appendix B.

The ontological analysis of BPMN allowed us to devise overall 12 measurement points, on the basis of the manifestations of ontological deficiencies identified in Table B1, that we could use to test the propositions. We note these 12 measurement points in our research model using solid arrows in Figure 1, which link these measurement points to PU and PEOU directly. The links allow us to examine, indirectly, the relationship between perceptions of a lack of completeness and clarity to perceived usefulness and perceived ease of use (indicated in Figure 1 through dashed arrows). We include measurement items for three manifestations of perceptions of construct deficit (as per Table B1—deficit related to the articulation of business rules, logs of state changes, process structure, and decomposition) so as to be able to gather data on proposition P1.

For proposition P2, we include measurement items for three manifestations of perceptions of construct redundancy (as per Table B1—redundancy related to the articulation of real-world objects, transformations and events); two manifestations of perceptions of construct overload (as per Table B1—overload related to the BPMN constructs Lane and Pool); and four manifestations of perceptions of construct excess (as per Table B1—excess related to the BPMN constructs Basic Event, Text Annotation, Off-Page Connector, and Multiple Instances). We select four manifestations of perceptions of construct excess out of the pool of ten potential excess candidate constructs (as per Recker et al. 2009) for the pragmatic reason of keeping our survey instrument as short as possible to avoid respondent drop-out. The four excess constructs we consider were selected following a previous interview-based study (Recker et al. 2010). This study examined which of the suggested excess constructs BPMN users avoided, used irregularly, or used frequently. On the basis of these findings, and to maintain consistency and avoid measurement bias, we decided in this study to include in the final survey items pertaining to two constructs that we found to be frequently in use and perceived as valuable if not essential to process modeling (*viz*., Text Annotation and Event) and two constructs that were frequently reported to be not in use or not well understood (*viz*., Off-Page Connector and Multiple Instances).

Overall, perceptual measurement scales were developed for each of the 12 measurement items and adopted to the specific context of each item.

In our study design, one further aspect required consideration. The fundamental premise that we seek to test in this study—that perceptions of ontological deficiencies of conceptual modeling grammars are negatively associated with a user's beliefs about the usefulness and ease of use of the grammar—rests on the assumption that users are aware of such grammar deficiencies. Yet, this assumption may not always hold in practice. For example, if a modeler never used the BPMN Lane construct, he/she would not have experienced a potential overload of this construct and would not associate such overload with decreased ease of use.

In order to account for potential perception gaps, for each of the 12 considered deficiencies, we had to establish whether or not respondents had encountered a situation in which such a deficiency would manifest (e.g., they were asked if they had ever used the BPMN Pool construct, whether they ever had the need to model business rules, and so forth). Only when they answered "yes" to these questions were respondents asked to fill out the measurement scales for the perceived deficiency. Including this extra question allowed us to identify two groups of respondents, those who experienced a situation in which a deficiency of BPMN may manifest, and those who did not. This design, in turn, allows us to pair-wise cross-examine the beliefs of perceived usefulness and perceived ease of use, as discussed below. Appendix A shows how we questioned the respondents and Table 2 gives the results.

Scale Validation

To avoid potential interpretational confounding, we assessed the validity of our empirical indicators in a measurement model before proceeding with the data analysis, following the suggestions by Segars and Grover (1993). Scale validation was performed via confirmatory factor analysis implemented in LISREL 8.80 (Jöreskog and Sörbom 2001). Each scale item was modeled as a reflective indicator of its theorized latent construct, and the measurement model included all 14 latent constructs. The constructs were allowed to covary in the measurement model.

Given that respondents did not necessarily experience all modeling situations associated with the ontological deficiencies in which we are interested, our dataset invariably contained empty data cells (see Table 2), namely those cells associated with perceptions of ontological deficiencies. This missing data is not missing at random, and is indicative of a theoretical meaning—namely, that respondents did not encounter one or more modeling situation in which an ontological deficiency should manifest. Case- or list-wise deletion strategies of the data cells would, therefore, bias the results from a measurement or structural model estimation exercise (Little and Rubin 2002). Furthermore, the subset of responses that experienced all twelve theorized modeling situations would have been too small for a meaningful statistical analysis (in total: 37 responses; see Table 2).

Table 2. Relative Sample Size per Type of Deficiency in the BPMN Grammar†

Respondents	PCD	PCR	PCO	PCE	Total
Experienced any deficiency	482	504	490	511	471
Experienced one deficiency	117	93	81	63	
Experienced two deficiencies	223	162	409	153	
Experienced three deficiencies	142	249		161	
Experienced four deficiencies				134	
Experienced all deficiencies					37
Experienced no deficiency	46	24	38	17	57

†Total sample size: 528

Accordingly, we used a full information maximum likelihood imputation method on the basis of the EM algorithm (Dempster et al. 1977) to estimate the measurement model. This approach allowed us to estimate the most likely values for the empty data cells on the basis of responses gathered for all other data cells (i.e., on the basis of all information given in the data set; Waarts et al. 1991). This approach for estimating imputed values for missing data is appropriate because, in any incomplete dataset, the observed values provide indirect evidence about the likely values of the unobserved ones (Schafer and Olson 1998). Full information maximum likelihood imputation strategies are considered the most appropriate type of imputation strategy in terms of reducing analysis bias, reliability of the results (Myrtveit et al. 2001), and in terms of estimation efficiency, number of convergence failures, and risk of type-1 errors (Enders and Bandalos 2001). Consequently, measurement model estimation for scale validation proceeded in two steps. First, using LISREL, we computed the full information maximum likelihood estimates for the missing data values. The resulting imputed dataset contained the original observed values as well as the imputed values for the unobserved data. The imputed data included estimates, standard errors, and p-values, thereby incorporating the uncertainty with which the missing values were predicted from the observed ones.

In a second step, we then attempted to estimate the measurement model from the imputed dataset, using the typical maximum likelihood approach in LISREL. Item validation and model fit statistics were then computed based on the imputed data set. Appendix C gives item validation results and the corresponding factor correlation matrix. Goodness of fit statistics for the measurement model (GFI = 0.80, NFI = 0.90, NNFI = 0.90, CFI = 0.91, SRMR = 0.049, RMSEA = 0.07, χ^2 = 2936.75, df = 753, χ^2/df = 3.90) suggest acceptable yet improvable fit of the model to the imputed data set, considering the approximate benchmarks suggested by Im and Grover (2004).[2] We note a significant χ^2 test and a relatively low GFI value. A potential reason for the low GFI value can be seen in the use of the heuristics used to impute missing values. Nevertheless, some authors report values above 0.80 as representing reasonable fit (Doll et al. 1994). The χ^2 value is susceptible to sample size and other conditions (Hu and Bentler 1999), and the relative χ^2/df value somewhat approximates the target ratio of 3.0 suggested by Chin and Todd (1995). Still, the relatively low GFI value and the significance of the χ^2 test suggest that a respecification of the model may lend better fit to the data (Evermann and Tate 2009). Considering the χ^2 test together with the goodness of fit statistics, however, we can consider the results to be acceptable (Im and Grover 2004).

Based on the data obtained and displayed in the tables in Appendix C, four tests can be performed. First, to display unidimensionality and internal consistency reliability of scales, Cronbach's (1951) α should exceed 0.7 (Gefen et al. 2000). Table C2 shows that all constructs meet the tests of uni-dimensionality and internal consistency reliability. As a second test of reliability, we consider the composite reliability measure, ρc, which represents the proportion of measurement variance attributable to the underlying trait. Scales with ρc greater than 0.7 are reliable (Jöreskog and Sörbom 2001). Table C2 shows that all constructs met the required ρc cut-off value.

Convergent validity tests if measures that should be related are, in fact, related. It can be tested using three criteria suggested by Fornell and Larcker (1981):

(1) All indicator factor loadings (λ) should be significant and exceed 0.6.

[2] $\chi^2/df \le 2.0$, GFI ≥ 0.90, CFI ≥ 0.90, SRMR ≤ 0.10, NFI ≥ 0.90, and NNFI ≥ 0.90.

(2) Construct composite reliabilities ρc should exceed 0.7.

(3) Average variance extracted (AVE) by each construct should exceed the variance due to measurement error for that construct (i.e., AVE should exceed 0.50).

Table C1 shows that all factor loadings λ are significant at $p < 0.001$ and exceed the recommended threshold of 0.6. As reported in Table C2, AVE for each construct is higher than 0.8, suggesting that for all constructs AVE well exceeded the variance due to measurement error. Overall, the conditions for convergent validity were met.

Discriminant validity tests if measures that should not be related are unrelated. Fornell and Larcker recommend a test of discriminant validity, where the AVE for each construct should exceed the squared correlation between that and any other construct considered in the factor correlation matrix. Based on the data displayed in Table C3, the largest squared correlations between any pair of constructs within the measurement model was 0.27 (between PCD3 and PU), while the smallest obtained AVE value was 0.89 (PCR1). These results suggest that the test of discriminant validity was met.

Results

In order to collect data to answer our research question, and to examine propositions P1 and P2, we proceed as follows (see Figure 2).

First, we examine descriptive statistics to ascertain the extent to which users perceived manifestations of ontological deficiencies in the BPMN grammar to exist in situations where the theory predicts that they should. Then, using structural model analysis, we test whether and how the perceptions of ontological deficiencies are correlated with beliefs about the perceived usefulness and ease of use of the BPMN grammar. This testing allows us to examine the relative influence of these perceptions on the key usage beliefs perceived usefulness and ease of use. Last, using a univariate analysis, we examine whether beliefs about the perceived usefulness and ease of use of the BPMN grammar change when users perceive none, one, or multiple manifestations of ontological deficiencies to exist in the grammar. We now detail the conduct and results for each analysis.

In a first step, we consider the descriptive statistics in Table 2 to ascertain how many respondents experienced modeling situations that were associated with a particular manifestation of an ontological deficiency, or multiple manifestations of ontological deficiencies of a certain type, of BPMN.

Table 3 reports mean total factor scores for the deficiency perception measures for those groups of users that encountered modeling situations in which an ontological deficiency was predicted to manifest. Table 3 further describes the relevant sample sizes for these groups (column N).

Inspecting Table 3, we note that in all but 2 of the 12 groups of respondents (for the situations in which PCR2 and PCE2 should manifest) mean total factor scores for the perception measures of the corresponding deficiency were higher than the neutral middle anchor 4 of the Likert scale used. This result can be interpreted as providing indirect evidence that users, in situations where the theory predicts ontological deficiencies to manifest, indeed perceived these ontological deficiencies to exist. We note, however, that for deficiencies pertaining to construct redundancy (specifically, PCR2) and construct excess (specifically, PCE2), users did not have strong perceptions of the existence of these deficiencies (the mean total factor scores were lower than the neutral middle anchor 4). These results could be interpreted as suggesting that in these situations, users tended to disagree about the suggested deficiency.

Structural Model Analysis

In the next step, having established the extent to which grammar users encountered modeling situations in which ontological deficiencies are predicted to manifest, we now examine whether and how user perceptions of ontological grammar deficiencies are associated with perceptions of the grammar's usefulness and ease of use, as stipulated in the first leg of propositions P1 and P2 and visualized in Figure 1.

We tested the two propositions simultaneously using a structural equation modeling (SEM) approach implemented in LISREL Version 8.80 (Jöreskog and Sörbom 2001). The SEM approach is particularly appropriate for testing theoretically justified models (Gefen et al. 2000), as was the case in this study.

Using LISREL, we created one structural model that linked the independent variables (each of the 12 measurement points for PCD, PCR, PCO, and PCE) to the dependent variables PU and PEOU, and linked PEOU to PU, as depicted in Figure 1. Each indicator was modeled in a reflective manner.

Model estimation was performed using the full information maximum likelihood imputation method on the basis of the EM algorithm (Dempster et al. 1977). Figure 3 shows the results for the structural model estimation.

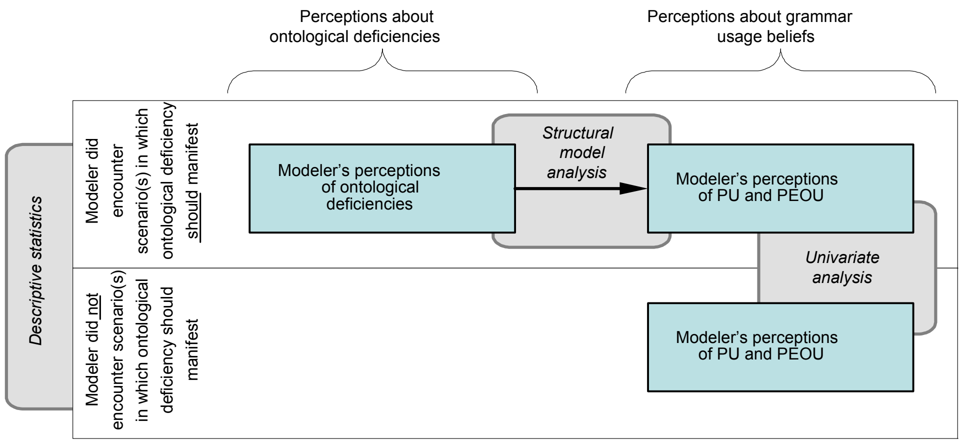

Figure 2. Data Analysis Strategy

Table 3. Means and Standard Deviations of Manifestations of Perceived Grammar Deficiencies†

Respondent Group	N	Mean	Standard Deviation
Users with a need to articulate business rules (PCD1)	395	4.62	1.46
Users with a need to articulate logs of state changes (PCD2)	183	4.11	1.55
Users with a need to articulate process structure and decomposition (PCD3)	412	4.95	1.22
Users with a need to articulate real-world objects (PCR1)	362	4.25	1.36
Users with a need to articulate transformations (PCR2)	326	3.91	1.53
Users with a need to articulate events (PCR3)	477	4.19	1.39
Users that have used the Pool construct (PCO1)	435	4.18	1.75
Users that have used the Lane construct (PCO2)	464	4.21	1.69
Users that have used the basic Event construct (PCE1)	430	4.66	1.54
Users that have used the Text Annotation construct (PCE2)	463	3.38	1.62
Users that have used the Off-page Connector construct (PCE3)	296	4.61	1.69
Users that have used the Multiple Instances construct (PCE4)	199	5.41	1.37

†Total sample size 528. Column N gives the sample size for the groups of respondents that encountered modeling situations in which a particular ontological deficiency was predicted to manifest. The groups of respondents that did not encounter modeling situations in which a particular ontological deficiency was predicted to manifest, therefore, is 528 – N.

In Figure 3, for visualization purposes, the dotted lines cluster the independent variables into the four groups of ontological deficiencies suggested by Wand and Weber (1993). Similar to the measurement model, goodness of fit statistics for the structural model (GFI = 0.81, NFI = 0.90, NNFI = 0.91, CFI = 0.92, SRMR = 0.041, RMSEA = 0.07, χ^2 = 2807.65, df = 740, χ^2/df = 3.79) suggest acceptable approximate fit of the model to the imputed data set (Im and Grover 2004).

Perusal of Figure 3 allows us to make the following observations. First, the squared multiple correlation (SMC) values show that the model accounts for 24.0 percent of the variance in perceived usefulness of the BPMN grammar, and for 12.1 percent of the variance in perceived ease of use. Examining the hypothesized paths in the model, Figure 3 shows that all three theorized paths between PCD measurement points and PU show the predicted directionality, and two of the three

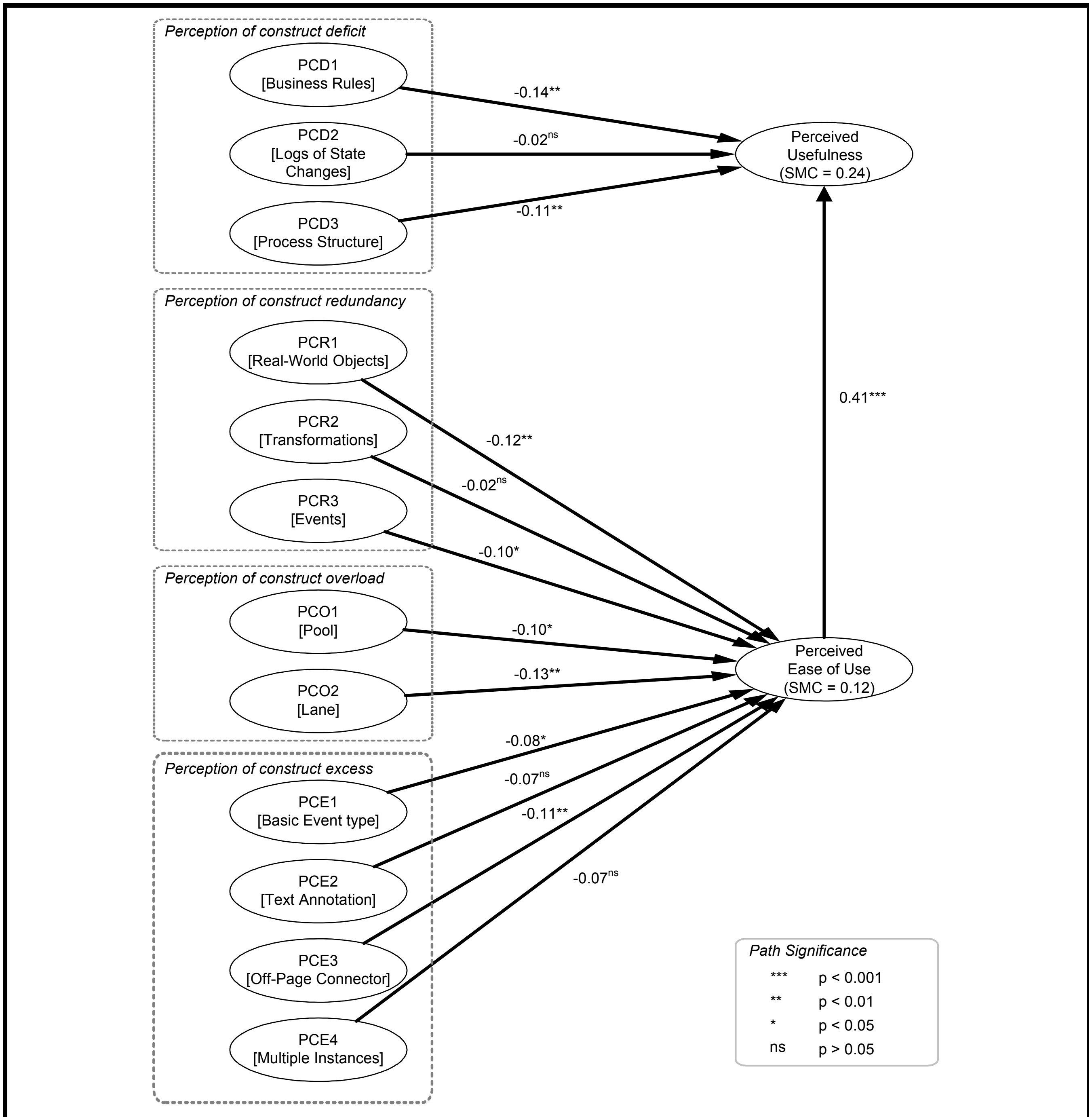

Figure 3. Structural Model Estimation Results

theorized paths between PCD measurement points and PU are statistically significant. The perceived usefulness of the BPMN grammar is significantly and negatively affected by the perceived deficit of BPMN in the articulation of business rules (γ = -0.14, $p < 0.01$) as well as BPMN's perceived deficit in the articulation of process structure and decomposition (γ = -0.11, $p < 0.01$). The perceived deficit in the articulation of logs of state changes has no significant impact on PU (γ = -0.02, $p > 0.05$). These results provide substantive, although not conclusive, support for proposition P1.

Figure 3 further shows that six of the nine theorized paths between PCR, PCO, and PCE and PEOU, respectively, were statistically significant. The perceived ease of use of the BPMN grammar was significantly and negatively affected by the perceived redundancy of BPMN in the articulation of real-world objects ($\gamma = -0.12$, $p < 0.01$) and, to a lesser extent, events ($\gamma = -0.10$, $p < 0.05$). PEOU was further significantly and adversely associated with the perceived overload of the BPMN Lane and Pool construct ($\gamma = -0.10$, $p < 0.05$, and $\gamma = -0.13$, $p < 0.01$) and also by the perceived lack of real-world meaning of the BPMN constructs Basic Event and Off-Page Connector ($\gamma = -0.08$, $p < 0.05$, and $\gamma = -0.11$, $p < 0.01$). Overall, these results provide some support for proposition P2. The link between perceived construct redundancy and PEOU showed the predicted negative directionality in all three cases, and support for these relationships was significant in two out of three cases. For the case of the link of PCR2 to PEOU, we note that the descriptive statistics suggested that users tended to disagree with the suggestion that the ontological deficiency should manifest in the predicted situations, which may explain the lack of significant support for the speculated association. The link between perceived construct overload and PEOU received support from the data in two out of two cases. The suggested link between perceived construct excess and PEOU, however, has inconclusive support from the data. Three out of four links showed the correct directionality (except for PCE2), but only two associations were significant. Albeit, we note that the link between PCE4 and PEOU only just missed the required significance level ($\gamma = -0.07$, $p = 0.06$), which may be due to the sample size. For the case of PCE2, we again note that the lack of support for the speculated link may be associated with the relatively low mean total factor scores for the deficiency perception measure (see Table 3). Indeed, both PCR2 and PCE2 received the lowest mean total factor scores across all deficiencies considered.

Last, we observe a significant and positive association between PEOU and PU ($\gamma = 0.41$, $p < 0.001$), consonant to findings from related studies about the use of conceptual models (e.g., Maes and Poels 2007) or the use of modeling grammars (Recker 2010a).

The findings from the structural model analysis show that 11 of the 12 theorized associations between perceptions of construct deficit, redundancy, overload, and grammar usage beliefs were found to show the correct directionality (except for PCE2). Moreover, eight of these associations were statistically significant (except for PCD2, PCR2, PCE2, and PCE4). This observation motivates us to tentatively accept the arguments provided in propositions P1 and P2. We note, however, that conclusions about the role, and impact, of perceptions of construct excess specifically require further analysis. For instance, we note that PCE4 received the highest mean total factor score (see Table 3) but failed to show a significant negative association to PEOU.

Univariate Analysis

Recall, not all users have encountered modeling situations where grammar ontological deficiencies would manifest (as shown in Table 2 and Table 3).

We speculate in propositions P1 and P2, first, that, for those users who have not encountered situations in which ontological deficiencies of BPMN would manifest, beliefs about the PU and PEOU of the BPMN grammar would be higher; and second, that the beliefs of PU and PEOU would decrease as the number of perceptions of manifestations of ontological deficiency increases. Following Figure 2, therefore, we examine whether PU and PEOU ratings change when a group of respondents faced none, one, or multiple deficiencies of a certain type (PCD, PCR, PCO, PCE). To that end, we used an analysis of variance (ANOVA) technique implemented in SPSS Version 16.0 (Bryman and Cramer 2008) to examine the differences in the average total factor scores for PU and PEOU between the different groups of respondents. We proceed as follows.

In a first step, we conducted two analyses. First, we conducted an ANOVA analysis with PCD manifestations encountered (yes/no) as the factor, and the average total factor score for PU as the dependent measure. Second, we conducted an ANOVA analysis with PCR, PCO, and PCE instances encountered (yes/no) as the factors, and the average total factor score for PEOU as the dependent measure. These two analyses allow us to examine, on a broad level, whether perceptions of ontological deficiencies impact PU and PEOU perceptions. Table 4 displays descriptive results from the analyses.

Table 5 gives the results from the significance tests. To deal with the α-inflation problem associated with separate data examinations, in Table 5 we report significance levels individually as well as using a Bonferroni adjustment (Shaffer 1995) to control for inflated type I error. This adjustment requires that the acceptable α-level (0.05) be divided by the number of comparisons made (in this case, two). For this first test, we consider a test statistic to be significant if the associated p-value is less than 0.025.

The results show that encountering PCD manifestations is a significant factor in explaining differences in PU ratings, and

Table 4. Means and Standard Deviations of Grammar Usage Beliefs, by Manifestations of Perceived Grammar Deficiency

Deficiency encountered	N	Mean	Standard Deviation
No PCD manifestation encountered	46	2.83 (PU)	1.53
One or more PCD manifestations encountered	482	2.11 (PU)	1.03
No PCR manifestation encountered	24	3.73 (PEOU)	1.46
One or more PCR manifestations encountered	504	2.92 (PEOU)	1.24
No PCO manifestation encountered	38	3.88 (PEOU)	1.44
One or more PCO manifestations encountered	490	2.89 (PEOU)	1.22
No PCE manifestation encountered	17	4.02 (PEOU)	1.45
One or more PCE manifestations encountered	511	2.93 (PEOU)	1.24

Table 5. Results from Significance Tests (Univariate Analysis)

Univariate ANOVA (PCD-PU)					
Source	**df**	**F**	**p**	**Sig. (with Bonferroni)**	**Eta Squared**
Corrected Model	1	18.62	0.00	Yes (yes)	0.03
Intercept	1	4396.12	0.00	Yes (yes)	0.89
PCD	1	18.62	0.00	Yes (yes)	0.03
Corrected Total	527			Yes (yes)	
Univariate ANOVA (PCR, PCO, PCE-PEOU)					
Source	**df**	**F**	**p**		**Eta Squared**
Corrected Model	7	5.93	0.00	Yes (yes)	0.17
Intercept	1	328.80	0.00	Yes (yes)	0.38
PCR	1	7.17	0.01	Yes (yes)	0.03
PCO	1	11.88	0.00	Yes (yes)	0.04
PCE	1	7.00	0.01	Yes (yes)	0.05
PCR * PCO	1	3.20	0.07	No (no)	0.06
PCR * PCE	1	0.56	0.46	No (no)	0.01
PCO * PCE	1	0.03	0.88	No (no)	0.00
PCR * PCO * PCE	1	1.09	0.30	No (no)	0.02
Corrected Total	527				

that encountering PCR, PCO, or PCE manifestations are significant factors in explaining differences in PEOU ratings. We further note that interaction effects between types of clarity deficiency manifestations are insignificant, indicating that the differences in PEOU ratings are clearly due to main effect perceptions of the clarity deficiencies and not to different types of deficiency interacting to produce an effect.

In a second step, we examine each deficiency and its impact on PU (or PEOU) in more detail. Our test examines whether there are differences in PU (or PEOU) perceptions when a respondent faces none, one, two, three, or even four manifestations of deficiencies. This test allows us to examine whether facing multiple deficiencies further decreases perceptions of the two considered usage beliefs. We first separate the respondents into groups depending on how many deficiencies of a certain type they perceive to exist. Between these groups, we then conduct ANOVA analyses using the contrast function (Bryman and Cramer 2008) to examine the significance of the relative changes in PU (or PEOU) ratings. The descriptive results from the analyses are summarized in Table 6.

Figure 4 displays graphically the results. In Figure 4, the X-axes display the number of instances of ontological deficiencies of a certain type perceived, while the Y-axes display the average rating of PU or PEOU. We note that all curves of PU (and PEOU) are decreasing as a function of the number of instances of ontological deficiencies of a certain type perceived, except for PEOU as a function of PCR manifestations (Figure 4b).

Table 7 gives the results from the significance tests. In Table 7 we report significance values independently as well as those under consideration of a Bonferroni correction that stipulates a relevant p-value of less than 0.0125 for differences to be significant across four independent tests. We see that significance levels meet the Bonferroni criterion in all cases but for PCE (in the contrast between one and no, and two and one perceptions).

Note that for the PEOU tests we use the ANCOVA technique in order to examine the effect of one type of deficiency (e.g., PCR manifestations) while examining potential interaction effects stemming from the other two types of deficiencies (e.g., PCO, PCE). In all three tests, we find the general model to be significant (p = 0.00), and each factor, and each covariate, to be significant, except for PCR not producing a significant interaction effect for the model PCE-PEOU.[3]

We make the following observations. We note that the results suggest that usefulness as well as ease of use perceptions of a grammar significantly differ depending on whether or not a grammar user has encountered none, one, or several situations in which ontological deficiencies (deficit, redundancy, overload, and/or excess) were predicted to manifest. This outcome is evidenced by all contrast results in Table 7 being significant, with the exception of perceptions of construct redundancy, where an increase in the number of redundancy perceptions from one to two did decrease PEOU ratings, albeit not significantly.

With this result in mind, still, we believe the results obtained from our ANOVA analyses provide further support for our propositions. PU rankings are in all cases significantly higher for the group of respondents that have not encountered any situation in which a theorized construct deficit of the modeling grammar would manifest (see Table 4 and Table 6 for the mean total factor scores of PU). Differences in PU rankings are significant between respondents that encounter none, one, two, or three situations in which construct deficit was theorized to manifest. These results are largely consistent with the findings obtained from the SEM analysis, and they provide further support for proposition P1.

Similarly, PEOU rankings were higher for the group of respondents that had not encountered a modeling situation in which an ontological clarity deficiency of the modeling grammar would manifest (see Table 4 and Table 6 for the mean total factor scores of PEOU). Again, differences in PEOU rating across groups of respondents that encountered none, one, or several deficiency situations are mostly significant, with the one exception in the case of two versus one perceptions of construct redundancy (similar to results obtained from the preliminary and structural model analysis). In conclusion, we believe the univariate analyses provide further evidence in support of propositions P1 and P2.

Discussion

This study provides empirical results on the associations that two types of characteristics of the BPMN modeling grammar (i.e., perceptions of a lack of ontological completeness and ontological clarity) have with user beliefs about the usefulness and ease of use of the modeling grammar. We summarize the evidence gathered on the two propositions P1 and P2 in Table 8 and assert that across all tests performed, the weight of evidence based on all analyses provides sufficient, consistent empirical evidence to support propositions P1 and P2.

The results in Table 8 show that eight of twelve hypothesized relationships received full support from the empirical tests, three received partial support, and one relationship received no support. The univariate analyses performed further showed largely significant support for the expected associations between deficiency perceptions and grammar usage belief perceptions.

[3]Significance levels for model PCR – PEOU [with PCO and PCE as covariates]: 0.01 [0.00, 0.01].

Significance levels for model PCO – PEOU [with PCR and PCE as covariates]: 0.00 [0.05, 0.00].

Significance levels for model PCE – PEOU [with PCR and PCO as covariates]: 0.01 [0.08, 0.00].

Table 6. Means and Standard Deviations of Grammar Usage Beliefs, by Number of Manifestations of Perceived Grammar Deficiency

Deficiency Encountered	N	Mean	Standard Deviation
No PCD manifestation encountered	46	2.83 (PU)	1.53
One PCD manifestation encountered	117	2.33 (PU)	1.19
Two PCD manifestations encountered	223	2.08 (PU)	0.89
Three PCD manifestations encountered	142	1.99 (PU)	1.10
No PCR manifestation encountered	24	3.73 (PEOU)	1.46
One PCR manifestation encountered	93	2.93 (PEOU)	1.23
Two PCR manifestations encountered	162	3.16 (PEOU)	1.25
Three PCR manifestations encountered	249	2.76 (PEOU)	1.21
No PCO manifestation encountered	38	3.88 (PEOU)	1.44
One PCO manifestation encountered	81	3.04 (PEOU)	1.31
Two PCO manifestations encountered	409	2.86 (PEOU)	1.20
No PCE manifestation encountered	17	4.02 (PEOU)	1.45
One PCE manifestation encountered	63	3.2 (PEOU)	1.31
Two PCE manifestations encountered	153	3.15 (PEOU)	1.35
Three PCE manifestations encountered	161	2.82 (PEOU)	1.17
Four PCE manifestations encountered	134	2.68 (PEOU)	1.10

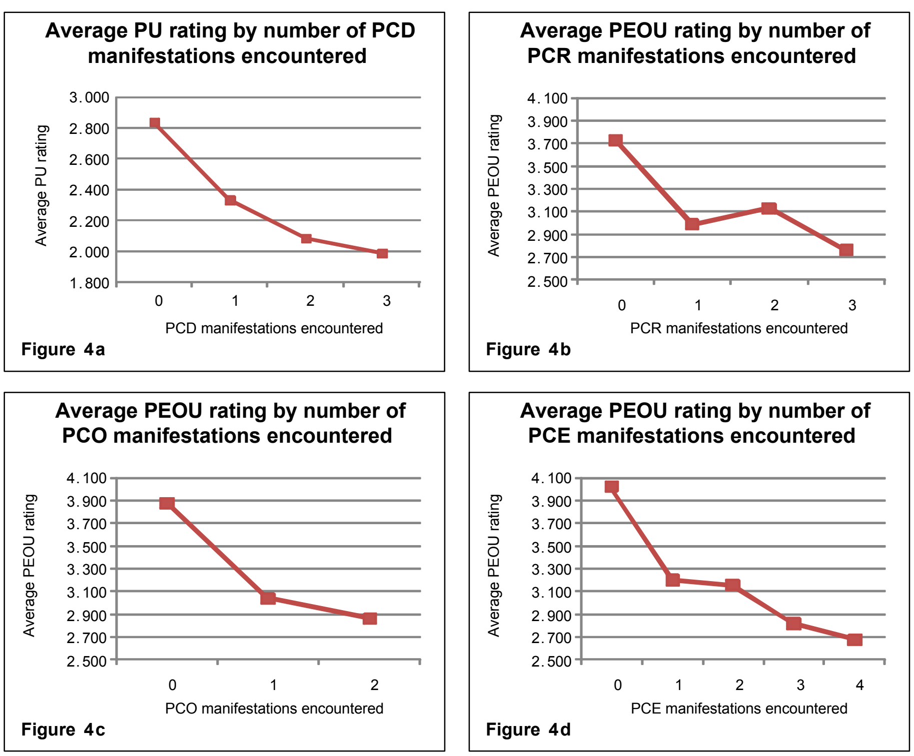

Figure 4. Results from ANOVA Analyses with Contrast

Table 7. Results from Significance Tests (Univariate Analysis with Contrast)

Contrast	Difference (Estimate-Hypothesized)	Std. Error	p	Sig. (with Bonferroni)
Univariate ANOVA with Contrast (PCD-PU)				
One PCD vs. no PCD	0.50	0.19	0.00	Yes (yes)
Two PCD vs. one PCD	0.50	0.12	0.00	Yes (yes)
Three PCD vs. two PCD	0.43	0.11	0.00	Yes (yes)
Univariate ANOVA with Contrast (PCR-PEOU, with PCO and PCE as covariates)				
Contrast	**Difference (Estimate-Hypothesized)**	**Std. Error**	**p**	**Sig. (with Bonferroni)**
One PCR vs. no PCR	0.80	0.27	0.00	Yes (yes)
Two PCR vs. one PCR	0.17	0.17	0.31	No (no)
Three PCR vs. two PCR	0.51	0.12	0.00	Yes (yes)
Univariate ANOVA with Contrast (PCO-PEOU, with PCR and PCE as covariates)				
Contrast	**Difference (Estimate-Hypothesized)**	**Std. Error**	**p**	**Sig. (with Bonferroni)**
One PCO vs. no PCO	0.84	0.24	0.00	Yes (yes)
Two PCO vs. one PCO	0.60	0.14	0.00	Yes (yes)
Univariate ANOVA with Contrast (PCE-PEOU, with PCR and PCO as covariates)				
Contrast	**Difference (Estimate-Hypothesized)**	**Std. Error**	**p**	**Sig. (with Bonferroni)**
One PCE vs. no PCE	0.82	0.34	0.02	Yes (no)
Two PCE vs. one PCE	0.46	0.20	0.02	Yes (no)
Three PCE vs. two PCE	0.64	0.15	0.00	Yes (yes)
Four PCE vs. three PCE	0.62	0.14	0.00	Yes (yes)

Table 8. Study Results

Proposition	Hypothesized Relationships	Empirical Findings
P1 Perceptions of a lack of ontological completeness negatively affect perceived grammar usefulness.	PCD1 [Business rules] → PU	Full Support
	PCD2 [Logs of state changes] → PU	Partial Support
	PCD3 [Process structure] → PU	Full Support
P2 Perceptions of a lack of ontological clarity negatively affect perceived grammar ease of use.	PCR1 [Real-world objects] → PEOU	Full Support
	PCR2 [Transformations] → PEOU	Partial Support
	PCR3 [Events] → PEOU	Full Support
	PCO1 [Pool] → PEOU	Full Support
	PCO2 [Lane] → PEOU	Full Support
	PCE1 [Basic Event type] → PEOU	Full Support
	PCE2 [Text Annotation] → PEOU	No Support
	PCE3 [Off-page connector] → PEOU	Full Support
	PCE4 [Multiple Instances] → PEOU	Partial Support

Key: **Full Support:** Correct directionality of, and significant evidence for, relationship.
Partial Support: Correct directionality of, but insignificant evidence for, relationship.
No Support: Incorrect directionality of, and insignificant evidence for, relationship.

In light of these results, we therefore suggest the tentative conclusion that manifestations of ontological grammar deficiencies, when perceived by users, are negatively associated with ease of use and usefulness perceptions of a grammar. PU and PEOU have recently been shown to be strong predictors of continued usage intentions associated with modeling grammars (Recker 2010a), which underlines the instrumentality of this finding.

While our results, in general, support this interpretation, our findings also inform some boundaries to consequential conclusions. In two cases (PCD2 and PCR2), the perceptions of construct deficit and construct redundancy showed a correct directionality of the hypothesized relationships to PU and PEOU, but without significant support from the data. Moreover, we found mixed and inconclusive support for the argument that perceptions of construct excess in the BPMN grammar are negatively associated with ease of use perceptions. While we found that users who did not use constructs that are classified as excess had higher perceptions of the ease of use of the grammar (see Table 6), the differences in PEOU ratings between the groups were not always significant.

Two related studies can assist in providing an explanation for the inconsistencies found. An exploratory study on BPMN use (Recker et al. 2010) identified situations in which the excessive constructs were actively used by modelers to mitigate other deficiencies in the modeling grammar. For example, we found that the BPMN Text Annotation construct was actively used to represent business rules given the lack of support for business rule modeling stemming from construct deficit in BPMN. Similarly, the study by zur Muehlen and Recker (2008) found some constructs classified as excess by Wand and Weber's (1993) theory, such as Text Annotation, Gateway types, and Association Flow, to be among the most frequently used constructs in BPMN modeling practice. One possible interpretation of these results is that some of the excess constructs in BPMN (e.g., Association Flows or Text Annotations) are used by modelers to mitigate or mask other deficiencies (e.g., construct deficit or overload). These workarounds may distort the theoretically hypothesized results, in that users may have positive usage perceptions about some of the excess constructs. For example, a modeler may find the excess construct Text Annotation useful because it allows them to handle other deficiencies of the grammar (for instance, those relating to the deficit for articulating business rules).

Our findings permit further speculation about how much perceptions of a lack of ontological capabilities matter to perceptions of usefulness and ease of use. The results show that the variance explained in PEOU (0.12) and PU (0.24) is moderate (Cohen 1988), yet congruent to other studies with similar predictive validity (e.g., Ahuja and Thatcher 2005; Fichman 2001). The validity of these results has been threatened by missing data. In our structural model analysis, we used a full information maximum likelihood imputation technique to alleviate potential concerns, yet we acknowledge that the resulting dataset may include imputation bias. To examine the potential bias, we compared the results obtained from the imputed dataset against those obtained by estimating four individual structural models, one for each type of ontological deficiency. We found the overall pattern of results to be similar, increasing our confidence in the results obtained. Therefore, we contend that our analysis strategy largely mitigates potential bias stemming from missing data, and thus, we believe that the results add to our understanding of the factors that are associated with usefulness and ease of use perceptions of modeling grammars.

Limitations

We identify some limitations of our work. First, our empirical study builds upon an ontological analysis of the BPMN grammar, which may be susceptible to challenges about completeness, guidance, and objectivity (Green and Rosemann 2005). To mitigate these risks, we followed an extended methodology for ontological analysis, and used a multiple coder approach to display inter-coder reliability in the analysis. More details are given in Appendix B.

Still, the ontological analysis might have been performed differently. For instance, we suggested that a deficit of representation constructs in the BPMN grammar results in the inability of users to articulate business rules. While our empirical study corroborates our arguments, we cannot fully eliminate two types of bias that may still be present. It might be that respondents stating their problems with business rules were not missing representation constructs in the grammar but rather some other sort of grammar, tool, or means. Also, it might be that the identified construct deficit in the grammar could have other consequences that were not addressed in our analysis.

A second potential limitation stems from our selection of four excess constructs for which we developed measurement instruments. The inclusion of other excess constructs in BPMN (e.g., Gateway, Association Flow) could have led to other results. Specifically, in light of recent work about the ontological meaning of Gateway constructs in process modeling (Soffer et al. 2007), it may be worthwhile to examine perceptions about these constructs and their relationships to grammar perceptions about the usefulness and ease of use.

Finally, our empirical study is susceptible to limitations typically associated with the survey research method. Specifically, we note that survey results denote snapshots of behavior at one place and time, and cannot provide as strong evidence for causality between theorized constructs as a well designed experiment (Newsted et al. 1998). Also, we note the significance of the χ^2 test of our structural model and the relatively low GFI value as a limitation, indicating that *post hoc* modifications to the model could result in better fit to the data, thereby potentially further advancing the theoretical relationships identified in this paper (Evermann and Tate 2009).

Implications for Research

We identify several opportunities for future research that can extend the specific scope of our research.

First, we used Wand and Weber's theoretical work to speculate about ontological deficiencies of a conceptual modeling grammar. We interpret our results as providing evidence for the validity and usefulness of Wand and Weber's (1993) theory of ontological expressiveness in the study of conceptual modeling and associated phenomena. By establishing that practitioner's perceptions of grammar deficiencies are associated with beliefs about the usefulness and ease of use of the grammar, we argue that Wand and Weber's (1993) theory allows researchers to speculate faithfully about conceptual modeling practices, complexities, and outcomes, and that it has merits for assisting researchers in arriving at an informed opinion about the complexity that relates to conceptual modeling practices and outcomes. Still, ideally, researchers should examine multiple theoretical frameworks (Hadar and Soffer 2006). Future studies, therefore, may examine user perceptions of ontological deficiencies as predicted through other ontological models (e.g., Milton and Kazmierczak 2004). Or, future studies may collect data about reported grammar deficiencies without using an *a priori* theory to guide the data collection, and then use an ontological model or a different theoretical base to examine theoretically the reported deficiencies.

Second, we were able to link research on conceptual modeling on the basis of ontological considerations to behavioral streams of IS research that examine perceptual usage beliefs. Following this vein of research, further opportunities exist to broaden the understanding of how conceptual modeling is performed in practice. Confirming that ontological deficiencies matter to practitioners working with modeling grammars suggests a number of questions about grammar characteristics. Future research could, for instance, examine the potential links between perceptions of ontological grammar deficiencies and actual grammar usage measures such as individual modeling performance, actual ease of learning, or the actual quality of the modeling outcomes (e.g., the effectiveness of the model created).

Third, the reported SMC values for PEOU (0.12) and PU (0.24) suggest that perceptions of ontological deficiencies have an effect on PU and PEOU, but only to a moderate extent. It was not our intention to develop a comprehensive explanatory model for the PU and PEOU of a modeling grammar. Instead, we specifically considered the impact of ontological deficiencies of 12 specific grammar constructs in the selected modeling grammar, BPMN. A study of a more complete set of grammar constructs, and associated deficiencies, may thus obtain effect sizes for PU and PEOU that are higher than those reported.

Our specific study focus also presents an opportunity for further research to draw a more complete picture of the key factors that drive usefulness and ease of use beliefs of modeling grammars. Similar to the work by Wixom and Todd (2005), we focused on the relationships between object-based beliefs (ontological grammar deficiencies) and behavioral beliefs (use of the grammar), omitting organizational, contextual, or personal factors (such as habit, experience, tool support, organizational conventions, and self-efficacy) that might add to our understanding of grammar usage beliefs. Such work, in addition to the work presented in this paper, may lead the way to advance conceptual modeling knowledge further towards normative or design-oriented advice.

Last, we turn to the inconclusive results about construct excess and its relationship to grammar beliefs. Future research is required to examine construct excess in more detail. Such study could, for instance, build on Soffer et al.'s (2007) examination of compositions of excess constructs in process modeling grammars. Soffer et al. showed that some of these compositions can form an ontologically meaningful construct. An opportunity exists to examine whether modelers recognize such ontologically meaningful compositions of excess constructs, whether these compositions alleviate deficiencies attributed to the individual constructs, and how ease of use perceptions about the grammar may be affected. Also, future studies could examine whether, and how, excess constructs are used in practice as workarounds for other grammar deficiencies (Recker et al. 2010), how their use as workarounds impacts usefulness and ease of use perceptions about these constructs, and how these beliefs affect overall beliefs about the grammar.

Implications for Practice

In addition to the work's academic merits, we identify significant implications for practice. Most notably, our findings can be used to guide modeling grammar (re-)development. Specifically, our results imply that developers of conceptual grammars, and methodologists in organizations, should pay attention to ontological characteristics. Similarly, extensions of existing modeling grammars and their implementations in modeling tools should be performed with a view of eliminating ontological deficiencies in the grammar. Two main implications arise.

First, to warrant positive usefulness beliefs about a modeling grammar, grammar (re-)development should attempt to eliminate construct deficit in the grammar. For the BPMN grammar, for instance, we identify a need to extend the modeling capabilities to provide better representational support for articulating business rules in graphical models. There are at least two ways to achieve this outcome. One way could be to complement the BPMN grammar with a business rule modeling grammar that allows for the representation of required ontological concepts to achieve maximum ontological coverage. An alternative way could be to inform the ongoing revision of the BPMN grammar (e.g., BPMI.org 2008) about this deficit of constructs, to motivate the specification of appropriate modeling means into the next release of the grammar.

Second, grammar development or extension should further consider ontological clarity, in order to improve the ease of using a grammar. There are at least two ways to achieve this aim. The semantics of modeling grammar constructs could be unambiguously defined in the grammar specification. Such an attempt, for instance, could alleviate concerns about the potential meanings of the Pool and Lane constructs in the BPMN grammar. A different attempt to alleviate clarity concerns could be to provide modeling tools with advanced functionality to filter and select modeling constructs to be used for model creation, thereby decreasing construct excess or redundancy in a grammar. The ARIS toolset (Scheer 1994), for instance, provides such functionality through a so-called method filter. Still, the reduction of modeling constructs should be considered not only before the background of ontological clarity as they may still be valid reasons to include additional constructs in a grammar even if they do not provide additional ontological expressiveness.

Aside from grammar (re-)development, our study informs providers of modeling training and analysts in charge of modeling conventions. One specific implication of our work is that grammar complexity (as indicated through manifestations of construct redundancy, overload, and/or excess) should be reduced, wherever possible, to alleviate cumbersome modeling work and to improve ease of use, a noted challenge for process modeling vendors specifically (Indulska et al. 2009). For instance, managers in charge of modeling conventions can use the findings of our study to define a restricted set of modeling grammar constructs to be used in modeling projects, so as to reduce potential construct redundancy in a grammar. Similar implications arise for the development of appropriate training methodologies, which, on the basis of the findings of our study, could teach modeling grammar use in a staged approach, where grammar constructs are first introduced to achieve good ontological coverage (to improve perceptions of the usefulness of the grammar) while avoiding ontologically unclear constructs (to warrant ease of learning). Ontologically unclear constructs may be taught at a later stage, after a certain level of modeling effectiveness and efficiency has already been established.

Last, our study examines whether ontological deficiencies matter to the practitioners working with conceptual modeling grammars. Our findings suggest that ontological deficiencies indeed do matter, albeit to a moderate extent only. We believe that these results suggest the relevance of Wand and Weber's work to informing a transfer of theoretical knowledge originating in academia to a body of knowledge in practitioner communities. One implication of our work is that modelers would benefit from certain ontological considerations in their modeling work. For instance, Wand and Weber's predictions can be used to inform trade-off decisions between expressiveness and parsimony. Furthermore, a comparative understanding of the ontological expressiveness of alternative modeling grammars and their related impact on usage beliefs can inform modeling grammar and related tool selection processes in practice.

Conclusions

In this paper, we theorized and provided evidence for a relationship between perceptions of ontological deficiencies of modeling grammars and the beliefs about the usefulness and ease of use of a modeling grammar.

Our work is the first to provide evidence that perceptions about ontological deficiencies of conceptual modeling grammars are associated with key usage beliefs of users working with the grammars. This work, therefore, advances our collective understanding of behavioral beliefs associated with the conceptual modeling process, and how properties of the modeling artifacts used in this process are associated with these beliefs.

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MIS Quarterly

RESEARCH ARTICLE

DO ONTOLOGICAL DEFICIENCIES IN MODELING GRAMMARS MATTER?[1]

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Appendix A

Operationalization and Instrumentation of Constructs

Table A1. Operationalization of Constructs

Construct	Operational Definition	Measurement
Perceived usefulness	The degree to which a person believes that a conceptual modeling grammar will be effective in achieving the intended modeling objective.	Extended from Moody's (2003) perceived usefulness scale.
Perceived ease of use	The degree to which a person believes that using a conceptual modeling grammar would be free of effort.	Adapted from Davis' (1989) perceived ease of use scale.
Perceived construct deficit	The extent to which a user perceives a conceptual modeling grammar to have a deficit of constructs that she would require to describe all real-world phenomena that she seeks to have represented in a conceptual model.	New scale developed (Recker and Rosemann 2010).
Perceived construct redundancy	The extent to which a user perceives a conceptual modeling grammar to provide more constructs than required to describe a single real-world phenomena that she seeks to have represented in a conceptual model.	New scale developed (Recker and Rosemann 2010).
Perceived construct overload	The extent to which a user perceives a conceptual modeling grammar to provide constructs that can each be used to describe more than one single real-world phenomena in a conceptual model.	New scale developed (Recker and Rosemann 2010).
Perceived construct excess	The extent to which a user perceives a conceptual modeling grammar to provide constructs that do not describe any relevant real-world phenomena in a conceptual model.	New scale developed (Recker and Rosemann 2010).

Survey Instrument

Demographics

Prior modeling experience

EXP1. Over your working life, roughly, how many years experience do you have in process modeling overall? *[number of years]*

EXP2. Over your working life, roughly, how many process models do you think you have created with BPMN? *[number of models created]*

Ontological Deficiencies

BPMN's support for modeling business rules

A business rule is a statement that defines the constraints and conditions governing processes, actions and procedures within a business. They are, for example, used to initiate processes or to specify discrete decision steps in a process.

PCD1_0. Have you ever had the need to represent business rules in a process model? *[Yes/No]*

PCD1_1. BPMN does not provide sufficient symbols to represent business rules in process models. *[Seven-point Likert scale]*

PCD1_2. BPMN could be made more complete by adding new symbols for representing business rules in process models. *[Seven-point Likert scale]*

PCD1_3. I often cannot use BPMN to adequately represent business rules in process models. *[Seven-point Likert scale]*

BPMN's support for modeling logs of state changes

A log of state changes is a document that captures all statuses that an entity has traversed in its lifecycle. Such information can be viable to recovery and reliability of interacting entities or systems. It can, for example, be used to track the messages that have been exchanged in a collaborative process.

PCD2_0. Have you ever had the need to represent logs of state changes in a process model? *[Yes/No]*

PCD2_1. BPMN does not provide sufficient symbols to represent logs of state changes in process models. *[Seven-point Likert scale]*

PCD2_2. BPMN could be made more complete by adding new symbols for representing logs of state changes in process models. *[Seven-point Likert scale]*

PCD2_3. I often cannot use BPMN to sufficiently represent logs of state changes in process models. *[Seven-point Likert scale]*

BPMN's support for modeling the structure of the modeled process

Process models can be systematically structured into constituent parts on different levels of abstraction. Graphically articulating the process structure and decomposition in a process model can help to clarify the scope, inner structure and decomposition of the modeled process.

PCD3_0. Have you ever had the need to represent the process structure and decomposition in a process model? *[Yes/No]*

PCD3_1. BPMN does not provide sufficient symbols to represent the process structure and decomposition in process models. *[Seven-point Likert scale]*

PCD3_2. BPMN could be made more complete by adding new symbols for representing the process structure and decomposition in process models. *[Seven-point Likert scale]*

PCD3_3. I often cannot use BPMN to adequately represent the process structure and decomposition in process models. *[Seven-point Likert scale]*

BPMN's support for modeling real-world objects

A real-world object is any entity, real or imaginary, for which an instance can be identified. There are potentially many different real-world objects that can be described in a process model. These include, for instance, a specific process participant (e.g., Supplier LA420), a specific staff member involved in the process (e.g., Bob the Builder), a certain instance of a document that is processed (e.g., the invoice No. 47-11), or a specific IT application (e.g., the accounting system XYZ) that is being used in a process.

PCR1_0. Have you ever had the need to represent types of real-world objects in a process model? *[Yes/No]*

PCR1_2. I often have to choose between a number of BPMN symbols to represent one kind of a real-world object in a process model. *[Seven-point Likert scale]*

PCR1_3. BPMN often provides two or more symbols that can be used to represent the same kind of real-world object in a process model. *[Seven-point Likert scale]*

PCR1_4. In a process model, one kind of a real-world object can often be represented by different BPMN symbols. *[Seven-point Likert scale]*

BPMN's support for modeling transformations

A transformation is a mapping between two states of an object and denotes a point in time at which certain changes occur to an object. An example for a transformation is the activity of processing a credit card application, which leads to a change in the status of the application from the value "in progress" to "approved" or "rejected."

PCR2_0. Have you ever had the need to represent types of transformations in a process model? *[Yes/No]*

PCR2_1. I often have to choose between a number of BPMN symbols to represent one kind of a transformation in a process model. *[Seven-point Likert scale]*

PCR2_2. BPMN often provides two or more symbols that can be used to represent the same kind of transformation in a process model. *[Seven-point Likert scale]*

PCR2_3. In a process model, one kind of a transformation can often be represented by different BPMN symbols. *[Seven-point Likert scale]*

BPMN's support for modeling events

An event may occur at the start, during, or at the end of a process. The occurrence of an event always leads to a change in the state of an object and creates a need for reacting to the event. For example, a phone call from a customer arrives, which causes a particular staff member to fill out a new credit card application.

PCR3_0. Have you ever had the need to represent events in a process model? *[Yes/No]*

PCR3_1. I often have to choose between a number of BPMN symbols to represent one kind of an event in a process model. *[Seven-point Likert scale]*

PCR3_2. BPMN often provides two or more symbols that can be used to represent the same kind of event in a process model. *[Seven-point Likert scale]*

PCR3_3. In a process model, one kind of a real-world object can often be represented by different BPMN symbols. *[Seven-point Likert scale]*

The use of the Pool symbol in BPMN

The BPMN symbol Pool is used to represent different participants in a modeled process. A participant can be a specific business entity (e.g., a company) or a more general business role (e.g., buyer, seller,or manufacturer). Graphically, a Pool is a container for partitioning a process from the other Pools, when modeling business-to-business situations, although a Pool need not have any internal details and may merely act as a black box.

PCO1_0. Have you ever used the Pool symbol in a process model? *[Yes/No]*

PCO1_1 I often have to provide additional information to clarify the context in which I want to use the Pool symbol in a process model. *[Seven-point Likert scale]*

PCO1_2 The Pool symbol can have more than one meaning in a process model. *[Seven-point Likert scale]*

PCO1_3 I often use the Pool symbol to represent more than one type of real-world phenomena in a process model. *[Seven-point Likert scale]*

The use of the Lane symbol in BPMN

The BPMN symbol Lane is used to organize and categorize activities within a Pool. Lanes are often used for such things as internal roles (e.g., manager, associate), application systems (e.g., accounting system, enterprise system) or an internal department (e.g., shipping, finance).

PCO2_0. Have you ever used the Lane symbol in a process model? *[Yes/No]*

PCO2_1. I often have to provide additional information to clarify the context in which I want to use the Lane symbol in a process model. *[Seven-point Likert scale]*

PCO2_2. The Lane symbol can have more than one meaning in a process model. *[Seven-point Likert scale]*

PCO2_3. I often use the Lane symbol to represent more than one type of real-world phenomena in a process model. *[Seven-point Likert scale]*

The use of the Basic Event symbol in BPMN

The basic Event symbol is general so as to cover many events that affect the flow of the process and have a cause or an impact. The Basic Event symbol is a open-centered circle without an internal marker that would differentiate different triggers or results.

PCE1_0. Have you ever used the Basic Event symbol in a process model? *[Yes/No]*

PCE1_1. The Basic Event symbol does not have a real-world meaning in a process model. *[Seven-point Likert scale]*

PCE1_2. I often cannot precisely ascribe a real-world meaning to the Basic Event symbol in a process model. *[Seven-point Likert scale]*

PCE1_3 The Basic Event symbol does not represent any relevant real-world phenomenon in a process model. *[Seven-point Likert scale]*

The use of the Text Annotation symbol in BPMN
The Text Annotation symbol is a mechanism to provide additional information for the reader of a BPMN model. A Text Annotation can be connected to any symbol in the model but does not affect the flow of the process.

PCE2_0. Have you ever used the Text Annotation symbol in a process model? *[Yes/No]*
PCE2_1. The Text Annotation symbol does not have a real-world meaning in a process model. *[Seven-point Likert scale]*
PCE2_2. I often cannot precisely ascribe a real-world meaning to the Text Annotation symbol in a process model. *[Seven-point Likert scale]*
PCE2_3. The Text Annotation symbol does not represent any relevant real-world phenomenon in a process model. *[Seven-point Likert scale]*

The use of the Off-page Connector symbol in BPMN
The Off-page Connector symbol is generally used for printing. This object will show where the Sequence Flow leaves one page and then restarts on the next page.

PCE3_0. Have you ever used the Off-page Connector symbol in a process model? *[Yes/No]*
PCE3_1. The Off-page Connector symbol does not have a real-world meaning in a process model. *[Seven-point Likert scale]*
PCE3_2. I often cannot precisely ascribe a real-world meaning to Off-page Connector symbol in a process model. *[Seven-point Likert scale]*
PCE3_3. The Off-page Connector symbol does not represent any relevant real-world phenomenon in a process model. *[Seven-point Likert scale]*

The use of the Multiple Instances symbol in BPMN
The Multiple Instances symbol is used to indicate a task that is performed multiple times during a process and needs to be executed in parallel repetitions. Multiple Instances describes a sequence in a process where several instances of one or several tasks are being generated in parallel.

PCE4_0. Have you ever used the Multiple Instances symbol in a process model? *[Yes/No]*
PCE4_1. The Multiple Instances symbol does not have a real-world meaning in a process model. *[Seven-point Likert scale]*
PCE4_2. I often cannot precisely ascribe a real-world meaning to the Multiple Instances symbol in a process model. *[Seven-point Likert scale]*
PCE4_3. The Multiple Instances symbol does not represent any relevant real-world phenomenon in a process model. *[Seven-point Likert scale]*

Usage Beliefs

Perceived Usefulness

PU1. Overall, I find BPMN useful for modeling processes. *[Seven-point Likert scale]*
PU2. I find BPMN useful for achieving the purpose of my process modeling. *[Seven-point Likert scale]*
PU3. I find BPMN helps me in meeting my process modeling objectives. *[Seven-point Likert scale]*

Perceived Ease of Use

PEOU1. I find it easy to model processes in the way I intended using BPMN. *[Seven-point Likert scale]*
PEOU2. I find learning BPMN for process modeling is easy. *[Seven-point Likert scale]*
PEOU3. I find creating process models using BPMN is easy. *[Seven-point Likert scale]*

Appendix B

Ontological Analysis of the BPMN Grammar

To perform the ontological analysis of the BPMN grammar, in a first step, we performed a representation mapping of BPMN grammar constructs to the ontological constructs specified in Wand and Weber's ontological model of representation to identify those mappings that are not isomorphic. Details about the mapping process are available in Recker et al. (2009). In performing the mapping, we followed an extended methodology for ontological analysis that allows for increasing the reliability and internal validity of such work (Green and Rosemann 2005). Specifically, our analysis was conducted in three steps. First, two of the authors separately read the BPMN specification and mapped the BPMN constructs against the ontological constructs in Wand and Weber's (1990) ontological model of representation in order to create individual first analysis mapping drafts. Second, the two researchers met to discuss and defend their mapping results. Third, the jointly agreed second draft was discussed and refined in several meetings with all four authors. By reaching a consensus at the end of this entire process, we increased the reliability and validity of this type of research.

In order to display inter-coder reliability in the mappings, two types of agreement statistics were derived. Both a raw percentage agreement (Moore and Benbasat 1991) and Cohen's (1960) Kappa were used to measure the agreement between the coders. Raw percentage agreement for the representation mapping of BPMN to ontological constructs between the two researchers involved was calculated to be 69 percent in the first round and 87 percent in the second round. We calculated Cohen's Kappa to be .62 in the first round and .83 in the second round, indicating sufficient reliability in both cases (Landis and Koch 1977). In the third round, the mapping was discussed and refined with all four researchers until a 100 percent agreement was obtained.

Based on the agreed mapping, we identified nine manifestations of ontological deficiencies existent in the BPMN grammar. We again performed the identification task first separately with two authors, then together, and last together with all four authors. For instance, we found construct overload in the Lane construct in BPMN, because the Lane construct maps to several ontological constructs described in Wand and Weber's representation model. Similarly, we identified several manifestations of construct redundancy (e.g., in the articulation of transformation or events), as several BPMN constructs map to the ontological concepts *transformation* or *event*. Table B1 provides an overview of all manifestations of ontological deficiencies identified in the BPMN grammar. The reasoning behind each identified manifestation of an ontological deficiency is available elsewhere (Recker et al. 2010; Recker et al. 2009).

Table B1. Identified Manifestations of Ontological Deficiencies in BPMN

Type of Deficiency	Identified Deficiency Manifestation as per Representation Mapping of BPMN*
Construct deficit	There is no BPMN representation for *state*, *stable state*, *unstable state*, *conceivable state space*, *state law*, *lawful state space*, *conceivable event space*, and *lawful event space*. Consequently, a sufficient focus to identify all important state and transformation laws may not be present during modeling processes with BPMN. Yet, these laws are the basis of business rules, which depict organizational policies and decision-making strategies pertaining to the execution of business processes and thus are essential to capturing the essence of a process. Specifically, the lack of support for the representation of conceivable and lawful state and event spaces indicates that modeling will be unclear to the modeler when trying to determine which set of states can potentially occur in a process upon occurrence of an event, which states are possible but should not be allowed, and which laws govern the transition across states in the occurrence of different events. This information, however, is typically the essence of business rules (in particular, event–condition–action and transformation rules; see Wagner 2005), which govern the state changes of process objects in the event of certain condition types that trigger different subsequent actions (i.e., transformations). Due to the lack of representation constructs for the abovementioned ontological constructs, **BPMN users will lack means for the specification of business rules in process models.**
	There is no BPMN representation for the ontological construct *history of state changes*. The specification of the history of states that a process object has traversed through its lifecycle, however, could be leveraged for a range of areas of process-related decision-making scenarios. Consider the case of credit history checks or customer relationship management processes, where key decisions are made on the basis of the history of the relevant process object (e.g., a credit card applicant or a frequent flier member). Accordingly, **BPMN users will lack means for the specification of a log of state changes in process models.**
	Because there is no representation for *system structure*, there is no thorough demarcation of the process system and the things within the system. We expect that users are unable to coherently articulate the breakdown of the modeled process system. Accordingly, **BPMN users will lack means for the specification of process structure and decomposition in process models.**

Table B1. Identified Manifestations of Ontological Deficiencies in BPMN	
Type of Deficiency	**Identified Deficiency Manifestation as per Representation Mapping of BPMN***
Construct redundancy	The BPMN Pool and Lane constructs share a capacity to represent a *thing*. Accordingly, **BPMN users will have difficulty understanding which BPMN construct to use for the graphical articulation of real-world objects in a process.**
	A *transformation* can be represented by the BPMN constructs Activity, Task, Collapsed Sub-Process, Expanded Sub-Process, Nested Sub-Process, and Transaction. Accordingly, **BPMN users will have difficulty understanding which BPMN construct to use for the graphical articulation of transformations in process models.**
	An *event* can be represented by nine BPMN constructs (i.e., Start Event, Intermediate Event, End Event, Message, Timer, Error, Cancel, Compensation, and Terminate). Accordingly, **BPMN users will have difficulty understanding which BPMN construct to use for the graphical articulation of events in process models.**
Construct overload	The BPMN construct Lane maps to the ontological constructs *thing*, *class*, *kind*, *system*, *subsystem*, *system composition*, *system environment*, *system decomposition*, and *level structure.* Accordingly, **BPMN users will have difficulty specifying exactly which real-world phenomenon is being graphically articulated by the Lane construct in a process model.**
	The BPMN construct Pool maps to the ontological constructs *thing*, *system*, *subsystem*, *system composition*, *system environment*, *system decomposition*, and *level structure.* Accordingly, **BPMN users will have difficulty specifying exactly which real-world phenomenon is being graphically articulated by the Pool construct in a process model.**
Construct excess	The BPMN constructs Link, Off-Page Connector, Association Flow, Text Annotation, Group, Activity Looping, Multiple Instances, Normal Flow, Event (super type), and Gateway (including all Gateway types) do not have a mapping to any ontological construct in Wand and Weber's ontological model. Accordingly, **BPMN users will have difficulty specifying exactly the meaning and purpose of these constructs in a process model.**

*Italicized terms denote constructs in Wand and Weber's (1990) ontological model.

Appendix C

Scale Validation Results

Table C1. Item Loadings

Construct	Item	Item Loading	t-statistic (for λ)
Perceived Construct deficit_1 (PCD1) [Business Rules]	PCD1_1	0.92	26.96
	PCD1_2	0.86	27.08
	PCD1_3	0.89	26.96
Perceived Construct deficit_2 (PCD2) [Logs of state changes]	PCD2_1	0.92	24.76
	PCD2_2	0.87	25.34
	PCD2_3	0.90	24.76
Perceived Construct deficit_3 (PCD3) [Process structure]	PCD3_1	0.94	37.23
	PCD3_2	0.87	33.50
	PCD3_3	0.91	37.22
Perceived Construct redundancy_1 (PCR1) [Real-world objects]	PCR1_1	0.82	22.08
	PCR1_2	0.89	21.91
	PCR1_3	0.87	22.08
Perceived Construct redundancy_2 (PCR2) [Transformations]	PCR2_1	0.83	27.44
	PCR2_2	0.89	29.79
	PCR2_3	0.91	27.43
Perceived Construct redundancy_3 (PCR3) [Events]	PCR3_1	0.92	31.01
	PCR3_2	0.94	33.16
	PCR3_3	0.88	31.01
Perceived Construct overload_1 (PCO1) [Pool]	PCO1_1	0.81	30.35
	PCO1_2	0.87	31.15
	PCO1_3	0.84	30.36
Perceived Construct overload_2 (PCO2) [Lane]	PCO2_1	0.88	31.85
	PCO2_2	0.80	33.62
	PCO2_3	0.83	31.94
Perceived Construct excess_1 (PCE1) [Basic Event type]	PCE1_1	0.89	39.49
	PCE1_2	0.89	31.65
	PCE1_3	0.92	39.49
Perceived Construct excess_2 (PCE2) [Text annotation]	PCE2_1	0.91	36.37
	PCE2_2	0.85	30.99
	PCE2_3	0.92	36.37
Perceived Construct excess_3 (PCE3) [Off-page connector]	PCE3_1	0.93	42.98
	PCE3_2	0.95	43.60
	PCE3_3	0.92	43.96
Perceived Construct excess_4 (PCE4) [Multiple Instances]	PCE4_1	0.94	27.45
	PCE4_2	0.92	27.15
	PCE4_3	0.91	28.81
Perceived Usefulness (PU)	PU1	0.80	30.33
	PU2	0.80	22.85
	PU3	0.78	24.01
Perceived Ease of Use (PEOU)	PEOU1	0.74	26.79
	PEOU2	0.86	31.16
	PEOU3	0.86	27.52

Table C2. Scale Properties

Construct	Number of Items	Cronbach's α	ρc	AVE
Perceived Construct deficit_1	3	0.87	0.85	0.92
Perceived Construct deficit_2	3	0.88	0.83	0.91
Perceived Construct deficit_3	3	0.93	0.88	0.94
Perceived Construct redundancy_1	3	0.87	0.81	0.89
Perceived Construct redundancy_2	3	0.91	0.86	0.93
Perceived Construct redundancy_3	3	0.90	0.88	0.93
Perceived Construct overload_1	3	0.92	0.86	0.93
Perceived Construct overload_2	3	0.91	0.86	0.93
Perceived Construct excess_1	3	0.93	0.87	0.93
Perceived Construct excess_2	3	0.92	0.88	0.94
Perceived Construct excess_3	3	0.97	0.92	0.96
Perceived Construct excess_4	3	0.95	0.91	0.95
Perceived Usefulness	3	0.87	0.82	0.91
Perceived Ease of Use	3	0.93	0.82	0.90

Table C3. Factor Correlations

	PCD1	PCD2	PCD3	PCR1	PCR2	PCR3	PCO1	PCO2	PCE1	PCE2	PCE3	PCE4	PU
PCD2	0.47												
PCD3	0.13	0.27											
PCR1	-0.07	-0.16	-0.09										
PCR2	-0.05	-0.04	-0.03	0.37									
PCR3	0.09	0.10	0.38	0.13	0.14								
PCO1	0.02	0.10	-0.17	-0.43	-0.07	-0.26							
PCO2	0.44	0.31	0.19	-0.23	-0.07	0.15	0.24						
PCE1	0.21	0.20	-0.01	0.12	0.24	0.07	-0.33	-0.06					
PCE2	0.31	0.26	0.08	0.22	0.08	0.12	0.02	0.12	0.19				
PCE3	-0.21	-0.32	0.11	0.20	-0.06	0.10	-0.10	-0.36	-0.20	-0.26			
PCE4	0.26	0.07	-0.13	-0.04	-0.07	0.08	-0.03	0.47	0.14	-0.06	-0.29		
PU	0.13	0.17	0.52	0.01	-0.11	0.48	-0.21	0.21	0.01	0.18	-0.01	-0.01	
PEOU	0.07	0.12	-0.19	-0.31	-0.08	-0.02	0.20	0.17	0.13	-0.09	-0.21	0.28	-0.07

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