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RESEARCH ARTICLE

DO ONTOLOGICAL DEFICIENCIES IN MODELING GRAMMARS MATTER?[1]

Jan Recker, Michael Rosemann
Faculty of Science and Technology, Queensland University of Technology, 126 Margaret Street,
Brisbane QLD 4000 AUSTRALIA {j.recker@qut.edu.au}, {m.rosemann@qut.edu.au}

Peter Green, Marta Indulska
UQ Business School, The University of Queensland, 11 Salisbury Road
Ipswich QLD 4305 AUSTRALIA {p.green@business.uq.edu.au}, {m.indulska@business.uq.edu}

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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