

# What we know and what we do not know about DMN

Kathrin Figl<sup>a</sup>, Jan Mendling<sup>\*,b</sup>, Gul Tokdemir<sup>c</sup>, Jan Vanthienen<sup>d</sup>

<sup>a</sup> University of Innsbruck, Austria

<sup>b</sup> Wirtschaftsuniversität Wien, Vienna, Austria

<sup>c</sup> Cankaya University, Ankara, Turkey

<sup>d</sup> KU Leuven, Belgium

*Abstract.* The recent Decision Model and Notation (DMN) establishes business decisions as first-class citizens of executable business processes. This research note has two objectives: first, to describe DMN's technical and theoretical foundations; second, to identify research directions for investigating DMN's potential benefits on a technological, individual and organizational level. To this end, we integrate perspectives from management science, cognitive theory and information systems research.

**Keywords.** DMN • BPMN • Process Modeling

Communicated by A. Koschmider. Received 2017-06-18. Accepted after 2 revisions on 2018-03-14.

## 1 Introduction

The Decision Model and Notation (DMN) is a recent standard of the Object Management Group (2016). It complements the Business Process Model and Notation (BPMN) with a notation for modeling decision logic and dependencies between decisions and data elements. The specification formulates several goals, which can also be understood as hypothetical benefits: First, the notation should be readily understandable by both business users and technical developers. Second, it should be straight forward to transform it to artifacts that implement decision logic. Third, it should be easily usable together with BPMN. DMN enjoys an increasing uptake in industry and receives attention in academic research. However, empirical research on DMN is still scarce such that it is unclear to which degree the proclaimed benefits materialize.

The aim of this paper is to structure future research on DMN. Sect. 2 summarizes the background of DMN. Sect. 3 describes a research agenda for DMN, before Sect. 4 concludes the paper.

\* Corresponding author.

E-mail. jan.mendling@wu.ac.at

## 2 Background of DMN

DMN is a standard for representing operational decisions of day-to-day business operations. Such decisions are frequently taken and repetitive in nature, e. g., determining if a customer is eligible for an insurance cover. Common operational decisions often relate to the calculation and evaluation of business opportunities, risk management and fraud detection. DMN complements BPMN, which does not model the decision logic in detail. DMN decouples decisions and control flow logic and it opens room for dynamic management of decisions. In most of the process models, decisions are embedded within the models and scattered over process model constructs, eventually posing difficulty in maintainability (Janssens et al. 2016b). In this sense, DMN reduces complexity and provides a decision model which is more precise and clear (Bossuyt and Gailly 2017). In this way, DMN helps business users in controlling their processes and organizational decisions more efficiently and effectively by means of well-designed decision and information structures.

More specifically, DMN defines three aspects of decisions: the decision requirements level, the decision logic level, and the expression language.

Fig. 1 illustrates these levels by the help of an example on a seller's credit warranting process for a potential buyer. DMN can be used together with BPMN as shown in the figure or independent of business processes.

First, the *Decision Requirements Diagram* (DRD) represents the relationship between decisions through their information requirements and defines decision requirements through constructs of *Decision*, *Business Knowledge Model*, *Knowledge Source*, *Input Data*, *Information Requirement*, *Knowledge Requirement* and *Authority requirement* (Object Management Group 2016). In Fig. 1, the input data for decision making is obtained from two sources: namely Findex and Project Specs. There is one decision whose result is used in the business process Credit Sales and two intermediate decisions Credit Eligibility and Cheque Performance, which yield results as input for the final Credit Sales decision. Payable Cheque Criteria is based on due cheque payments of the buyer within one year with respect to project value and project payment term. Paid Cheque Criteria on the other hand depends on previous cheque payment history with respect to project value.

Second, the *Decision Logic Level* (DLL) represents the logic of a single decision in the form of a boxed expression. One of the most widely used representations for decision logic is a decision table, but other expressions are allowed, e. g. using analytical models, mathematical functions or decision rules. Decision tables define the production rules from input parameters to the output parameters. In Fig. 1, the decision logic for Credit Eligibility is shown as a decision table, in which the parameters Project Value, Total Credibility Amount, Available Credit Limit, Bank Credit Warrant Letter are used as input for determining the output parameter Credit Eligibility.

Third, DMN also standardizes the expression language FEEL (Friendly Enough Expression Language) and a simple subset S-FEEL for use in decision tables. FEEL defines a syntax for expressions, which permits the description of decision logic in terms of decision tables, analytical models, or business rules. At the bottom of Fig. 1, the

decision logic of Credit Eligibility is shown using FEEL syntax for the rules expressed in the table.

### 3 Research Agenda for Investigating DMN Benefits

In this section, we review the literature and discuss a research agenda for investigating the potential benefits of DMN. We structure this discussion by the help of the information systems research framework by Hevner et al. (2004), which identifies technology (Sect. 3.1), individual (Sect. 3.2) and organization (Sect. 3.3) as three relevant areas.

#### 3.1 Research Directions on Technological Benefits of DMN

The history of operational decision management and DMN finds its origin in decision table modeling, where rules for decision logic are represented in a structure of related tables, which map combinations of inputs to outcomes. Decision tables and the accompanying methodology have proven a powerful vehicle for acquiring the decision knowledge and for checking completeness, correctness and consistency (CODASYL Decision Table Task Group 1982). DMN builds upon these concepts and goes further by standardizing existing decision table formats (using a hit policy indicator), by elaborating the requirements diagram, and by introducing a standard expression language. Even though DMN standardizes and extends the modeling capabilities of decision requirements and decision logic (e. g. by adding FEEL), various results from previous research into decision tables can be readily adopted.

**Verification & Validation (V&V):** Verification and validation of rule-based systems (including decision tables) has been a major area of research, as exemplified by the earlier EUROVAV series of conferences (European Conference on Verification & Validation of Knowledge-based systems) (Antoniou et al. 1998). This is important because at the decision logic level, decision logic is often expressed in rules and tables. There are numerous works dealing with V&V of a set of rules (as present in

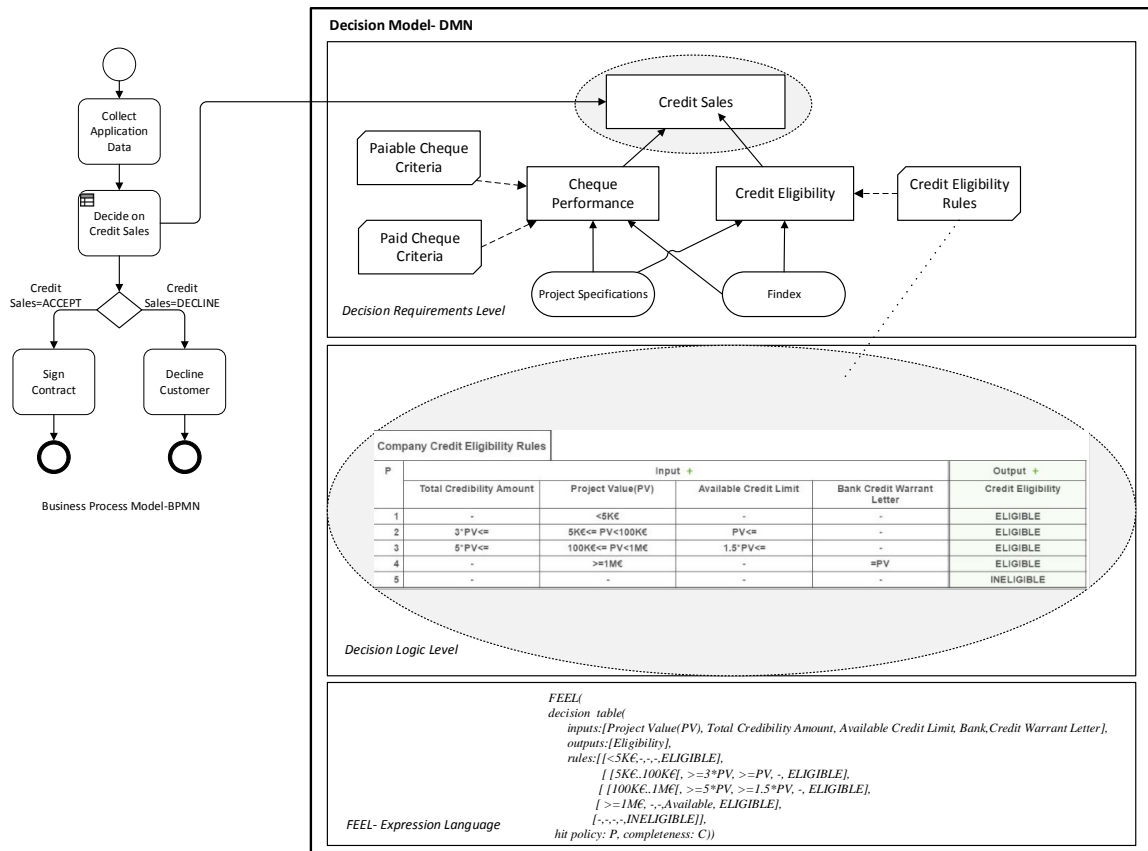


Figure 1: How DMN operates solely or in relation to BPMN. An example on Credit Sales.

single decision tables). Typical rule anomalies are: redundancy (including duplicates and subsumption), ambivalence, circularity, and deficiency (missing rules). Numerous algorithms are available for checking and eliminating contradictions, redundancies and missing rules for all possible values of the input variables. Other approaches have been designed to strictly avoid table anomalies by recommending unique single hit tables. Thus, there has been an increased interest and work in relation to verification and validation studies in literature within the last few decades. For example, various tools have already included anomaly detection algorithms (Hinkelmann 2016). In a similar manner, Calvanese et al. (2016) and Laurson and Maggi (2017) propose new algorithms to discover overlapping and missing rules during DMN table modeling task.

In terms of correctness of decision logic, Bataoulis et al. (2017) analyze process models with DMN by checking different soundness levels for decision-aware processes. For an overview of earlier research in this area, see Vanthienen et al. (1998), or more recently Calvanese et al. (2016).

**V&V over table networks:** Also, V&V of table structures has been covered in earlier research. When input conditions or outcomes are repeated in more than one decision, some parts of the decision logic in a certain decision may become unreachable or inconsistent for specific input values. Checking consistency and completeness between interconnected decision tables, i.e. over rule chains, is a much more challenging problem than verification of single tables.

See Vanthienen et al. (1997) for an overview of inter-tabular verification.

**Table Simplification:** Decision tables can be simplified and split up using normalization (Vanthienen and Dries 1994). The first type of simplification means that rules with equal condition inputs for all but one condition and with the same outcomes can be joined together, reducing the number of rules in the table. This is called table contraction, minimizing the number of rows for the given condition order. For this case, a recent study by Laurson and Maggi (2017) is a good example, where a rule merging algorithm is proposed for table simplification. One can also identify the order of the input conditions that leads to the most compact table, thereby optimizing the condition order. Another simplification is to split complex tables into more simple ones. Decision tables can (or should) be split up if the outcomes are not dependent on all the conditions. This is called factoring or normalization, analogous to normalization in relational database theory where attributes should be dependent on the key.

**Code Generation:** When properly specified using (S)FEEL, decision models and tables are executable, given that appropriate DMN tooling is available. This is a straightforward execution without further optimization. In a number of cases, however, attention could be paid to execution efficiency or more flexible forms of code generation. Since the early days of decision tables, a lot of work has been done in this area, by transforming decision tables into optimal code, by generating least-cost execution trees based on condition test times and case frequencies, see e. g. Lew (1978) or CODASYL Decision Table Task Group (1982).

**Decision Mining:** Operational decisions can be modeled in DMN by domain experts by using the domain knowledge present in e. g. rules, procedures, policies and regulations. But decision logic can also be derived from case data where the mined model is discovered or transformed

into a decision table (Baesens et al. 2003; Wets et al. 1998). Not unlike process models, which can be discovered from events logs, decision discovery is a form of knowledge discovery from logs containing historical data about case attributes and their outcome. Currently, decision mining is often limited to discovering the decision logic at a certain decision point in a process model, but a more complex challenge is the integrated mining of both a process and a decision model based on extensive decision process logs (Smedt et al. 2017a).

Accordingly, literature has provided numerous research on how to create an integrated model with decisions and processes. For example, Biard et al. (2015), in their study recommend defining a decision task for multiple gateways in the process model and constructing a decision model as a separated entity. They emphasize that DMN's scope is restricted to operational level decisions, instead of tactical ones, as they are related to pre-defined decisions. In the recent research, Bazhenova (2017) describes how to extract a decision model from process model based on split gateways and event logs. In another study, Batoulis et al. (2016) bring forward an approach to adjust decision logic dynamically, using event log information during process implementation by creating DMN model automatically that will improve process execution consequently. From an alternative perspective, van der Aa et al. (2016) create BPMN/DMN models based on data-flow structure automatically. Similarly, an approach for automatic DMN construction is defined by Bazhenova and Weske (2015), where decision logic has been extracted from event logs of a simple process model in banking domain. The research extracts decisions from process models based on local decision points and limited in terms of applying their proposal to simple process models in a specific domain. Mertens et al. (2017) introduce DeciClare, which is a mixed-perspective process modeling language. It is more for loosely framed processes which incorporates functional, control-flow, data and resource views and includes concepts of DMN

language for modeling data perspective. Hence, it provides a comprehensive view for integration of decisions and processes. In regard to composition and decomposition of processes and decisions, recent research mostly focuses on simpler process models, where decisions are local, and do not span across process elements other than gateways. However, complex process models, where decisions may extend over process modeling elements and where dependencies exist, a holistic approach is required for integrated modeling of processes and decisions (Hasic et al. 2018). While in literature the number of such research remains low, recent studies acknowledge this requirement and propose enhanced methods. For example, Smedt et al. (2017b) put forward a holistic approach for decision extraction from process models called Process Mining Integrating Decisions (P-MInD), which incorporates various business activities affecting the decision perspective.

DMN promises various benefits for the efficient and effective design and management of decisions, e. g. in business processes. As recent research suggests, decision modeling alongside business processes enables and helps business users to manage complexity (Janssens et al. 2016a; Taylor 2011). This better management of complexity should also help to support flexibility and maintainability of processes.

Research challenges arise in this context regarding the consistency between DMN and BPMN. How should decisions and processes be modeled in an integrated way? How can decisions and processes be mined together in a combined way to reveal entire decision structures? How can we transform decision logic from BPMN models to DMN? Answering these questions requires research methods that are grounded in formal science and design science.

### 3.2 Research Directions on Individual Benefits of DMN

In order to structure the discussion of DMN-related research problems on the individual level, we refer to a theoretical model by Gemino and Wand (2003) that describes modeling as a process

of knowledge construction. The outcome of this process is influenced by three major perspectives: First, the characteristics of model viewers in association with their tasks (Sect. 3.2.1); second, the content that is captured in the model (Sect. 3.2.2) and third, the presentation format of this content (Sect. 3.2.3). From a cognitive point of view, the content view relates to the inherent complexity of information that must be understood (Sweller 2010). While intrinsic cognitive load may not be easily altered without changing the decision situation, extraneous cognitive load can be decreased by how the decision model is presented and more cognitive effort can be devoted to schema construction (germane load) (Sweller 2010).

#### 3.2.1 Characteristics of Model Viewers

The DMN specification (Object Management Group 2016, p. 169) lists three types of possible user groups: business analysts, business users and technical developers. These user groups have different technical expertise and they focus either on creating or on reading DMN models, respectively.

**Novice versus Expert:** Prior research on conceptual modeling has investigated expertise from different angles. Studies including Schenk et al. (1998) have observed striking differences in the way how novice system analysts approach a project (rather bottom-up and opportunity-driven) as compared to expert system analysts (rather top-down and goal-oriented). There are various requirements for a person to transition from a novice to an expert status, likely also for DMN: learning the language and its concepts, developing patterns of how to capture recurring problems, and deliberate training over a longer period of time. The roles mentioned in Object Management Group (2016, p. 169), i. e. business analysts designing decisions, business users populating decision models and technical developers mapping business terms to appropriate data technologies have different skills and prior knowledge with respect to decision modeling. Also, the distinction of S-FEEL

for business users and full FEEL for advanced business analysts or developers emphasizes the different skill sets. Concerning domain expertise, decision making requires high levels of domain expertise (Bock 2015). Thus, in general, decisions modeled in DMN also have the advantage to externalize such knowledge for employees less familiar with a decision domain.

**Reading and Creating Models:** More generally, we know from research on expertise that being an expert is very much bound to a specific task (Ericsson and Lehmann 1996). Conceptual modeling research has distinguished the activities of creating and reading a model. In essence, a model viewer has to be familiar with the syntax and semantics of a notation like DMN in order to interpret individual models. The task of modelers is more challenging, since they have to transform ideas, observations and discussions into a correct representation. Tasks of verification and validation are highly important in this context, and different types of users might be unequally skilled for conducting them.

Besides foreseen advantages, the understandability of DMN by different stakeholders deserves profound attention. In this sense, adapting DMN into organizational decision making processes necessitates stakeholders like business analysts or IT professionals to get familiar with the notation. Research could suggest modifications to DMN to improve the notation and to shorten the learning curve of stakeholders in trainings. Questions arise here on how and in which circumstances users can most effectively work with DMN and which characteristics of users and models best facilitate understanding. Answering these questions requires research methods that are grounded in empirical research.

### 3.2.2 Semantic Content of DMN

The semantic constructs of DMN are defined by the metamodel and have already been discussed in the previous sections. Now, we want to outline some directions in which future research on

the cognitive difficulty of different semantic constructs could be pursued. Similar research has been conducted e. g. in the area of cognitive difficulty of control flow patterns used in process models (Figl and Laue 2015) or of different types of features and relations used in variability models (Reinhartz-Berger et al. 2014). If future research is able to determine valid and reliable values for the cognitive difficulty of understanding specific parts of decisions, such values could then be used to guide modeling tool developers to provide feedback on the cognitive difficulty of models to users. Model editors could calculate global metrics for the complexity of a decision, warn the modeler when they exceed a certain threshold and use color highlighting of models and decision tables to visually highlight difficult parts. Since DRGs do not depict detail information on how the decisions are exactly taken, we deem the investigation of the cognitive difficulty of decision tables more promising. For instance, future work could empirically assess whether unique/first hit/any hit or priority hit policies are more complex to understand and lead to higher error rates. While automated algorithms might check rule anomalies, still human comprehension of the rules is necessary for a variety of tasks.

### 3.2.3 Visual Presentation of DMN

When considering the visual presentation of DMN, we have to look separately at the three levels (DRD, DLL and FEEL). Although these levels are related to each other, their representation format—graphical models, tables and textual expression language—varies significantly. In the context of this paper, we focus on DRDs and decision tables, but do not discuss the FEEL, because it is mainly textual. We structure our discussion of the presentation of DMN into various sections based on the physics of notations framework (Moody 2009), which integrates different theoretical perspectives to define nine principles how to design visual notations that do not cause more cognitive load for users than necessary. These principles

are semiotic clarity, graphic economy, visual expressiveness and perceptual discriminability, semantic transparency, dual coding, cognitive fit, complexity management and cognitive integration. Furthermore, we add one aspects which is not explicitly defined at the notational level, but plays a critical role at the level of single diagrams: labeling and naming conventions (Leopold et al. 2013). We consider *primary notation* which would refer to the standard document published by OMG and relevant aspects of *secondary notation*, which relates to “things which are not formally part of a notation which are nevertheless used to interpret it” (Petre 2006, p. 293). Dangarska et al. (2016) have presented the first analysis of DRGs (decision tables were not evaluated) according to Moody’s framework based on an expert assessment. Besides expert evaluations, future research could e. g. conduct questionnaire-based studies to provide user evaluations of the symbol set of DMN, e. g. by using scales to assess semiotic clarity, perceptual discriminability, visual expressiveness or semantic transparency (see for instance evaluations of symbol sets of other modeling notations (Figl et al. 2010, 2013)). Another approach could be to develop symbol sets optimized based on cognitive design guidelines, which has been done for other existing notations (Genon et al. 2012, 2011) and compare their effect on comprehensibility with original DMN symbols. Moreover, usability tests and experiments including eye-tracking could be performed by researchers to assess the understandability of the visual notation of DMN. The following sections gives an background on relevant factors which could be included in experiments and highlights relevant open research questions.

### **Semiotic Clarity**

The principle of semiotic clarity demands that there is a 1:1 relationship between any semantic construct and the corresponding visual symbol the notation offers. One potential violation of this rule in the form of symbol redundancy (more than one visual representation for one and the same underlying semantic construct) can for instance be found

in the DMN notation (Object Management Group 2016, p. 31): “An alternative compliant way to display requirements for Input Data, especially useful when DRDs are large or complex, is that Input Data are not drawn as separate notational elements in the DRD, but are instead listed on those Decision elements which require them.” In the context of semantic constructs, a representational analysis according to the theory by Wand/Weber based on Bunge (Recker et al. 2011) may also be effective to highlight the concepts which DMN is supporting in contrast to other decision modeling notations. An interesting starting point for such an analysis might be a paper by Bock (2015), who has started to identify and compare semantic constructs for decision making in various visual modeling approaches, e. g. decision matrices, decision trees and influence diagrams. In comparison to other approaches, DMN has a strong focus on routine operational decisions and is less suitable to ambiguous, non-routine and novel decision situations (Bock 2015).

### **Graphic Economy**

In comparison to other modeling notations like BPMN, which offer a high number of symbols, DMN can be considered parsimonious because the size of its vocabulary it manageable (4 symbols, 3 types of edges for different requirements and a visual definition for using textual annotations for DRDs (Object Management Group 2016, p. 30)). Based on a theoretical approach analyzing the objects, relationships and properties of the meta-model, the cumulative complexity of DMN was rated “relatively low”, comparable to the modeling standard CMMN, but lower than BPMN, which offers higher expressive power (Hasic et al. 2017). In the authors’ assessment they conclude that “DMN should be simple to learn and understand” (Hasic et al. 2017, p. 69).

### **Visual Expressiveness and Perceptual Discriminability**

The use of visual variables for symbols (position, color, size, texture, shape, orientation, brightness) determines the visual expressiveness of a

notation. Pairwise differences of symbols on visual variables increase perceptual discriminability. In general, DMN uses rectangles to represent decisions and variations of rectangles for other concepts: e. g. for the concept *Knowledge Source* a “shape with three straight sides and one wavy one”, for *Business Knowledge Model* a “rectangle with two clipped corners” and for *Input Data* a “shape with two parallel straight sides and two semi-circular ends” (Object Management Group 2016, p. 31). *Requirements* differ according to the texture (dotted vs. solid lines) and type of arrowhead. Therefore, Dangarska et al. (2016) have rated visual expressiveness of DMN as low and perceptual discriminability as partly violated. Empirical research is necessary to find out whether low visual expressiveness and discriminability actually lead to problems for users to distinguish symbols.

### Semantic Transparency

Semantic transparency is determined by how easily the meaning of a visual appearance can be “inferred from its appearance ” (Moody 2009, p. 764). Dangarska et al. (2016) have given the core symbols an opaque score (indicating an “arbitrary relationship between appearance and meaning”), while arrows for *Requirements* were rated as immediate. Semantic transparency is also relevant for choosing spatial arrangements of elements that ease the comprehension of their relationship. The DMN standard does not give concrete instructions on how to arrange and layout DRDs. When looking at simple DRDs drawn in the standard document (Object Management Group 2016, p. 75), input data and sub-decisions are placed below decisions, business knowledge symbols are placed left and knowledge sources symbols are placed on the left and on the right above decisions. Empirical research could test whether placement of model elements has any effect on the comprehension of DRDs and whether there are positioning guidelines of elements which would result in easier to understand DRDs. In studies on interpreting diagrams with nonsense words “causes were always thought to lie to the

left of and above effects” (Winn 1990, p. 155). Thus, placing input data and sub-decisions to the left or above decisions might also be intuitively understandable. However, tree structures expanding from a parent node at the top or from the left are also widely-used conventions, supporting the exemplary spatial arrangement in the standard document (Object Management Group 2016, p. 75). Concerning the layout of decision tables the DMN standard document also gives users freedom of choice and states “a decision table can be presented horizontally (rules as rows), vertically (rules as columns), or crosstab (rules composed from two input dimensions)” (Object Management Group 2016, p. 75). However, the standard is quite clear on the positioning of input columns, which reflect the findings of Winn (1990) on intuitively understandable conventions of spatial arrangements: “In a horizontal table, all input columns SHALL be represented on the left of all output columns. In a vertical table, all the input rows SHALL be represented above all output rows” (Object Management Group 2016, p. 75).

### Dual Coding

While text should not be used to distinguish between symbols, it can be wise to supplement graphical information with it (Moody 2009). DMN actively encourages text annotations, using a dotted line and a square bracket. Furthermore, it gives clear advice on how to combine text, e. g. “the label . . . SHALL be clearly inside the shape of the DRD element” (Object Management Group 2016, p. 31). Such a guideline can theoretically grounded on the Gestalt law of common region, which posits “the tendency for elements that lie within the same bounded area to be grouped together” (Palmer et al. 2003, p. 312). However, user evaluations of business process models have shown that readers rate labels placed physically close to symbols equally well to labels placed inside a symbol (Figl 2017).



### Cognitive Fit

Moody (2009) suggests the use of different visual dialects for experts and novices as well as for different representational media in order to achieve cognitive fit. This is something DMN does not offer. However, DMN addresses the issue of cognitive fit in the wider sense since a main objective of DMN is to combine decision tables and requirements diagrams (DRDs) to account for the fact that both are well suited to represent different types of information elements for different tasks. Cognitive fit theory (Vessey and Galletta 1991) originates from the observation that graph versus table use is suited for different tasks. Still, it might be advantageous to offer users not only decision tables, but also decision trees as additional visualization to comprehend a complex decision. Vessey and Weber (1986) compared decision tables and decision trees in the context of a programming task and found decision trees to outperform decision tables. Similarly, decision trees were found to be more helpful when used in an investment game than the corresponding decision tables (Subramanian et al. 1992). However, for various comprehension tasks more recent experiments revealed that decision tables performed better than decision trees and textual rules (Huysmans et al. 2011). Overall, more work is needed to clarify inconsistencies of prior research and address whether offering decision tree visualizations in addition to decision tables as specified in DMN might enhance human comprehension.

### Complexity Management and Hierarchical Structuring of Decisions

To avoid overloading human working memory with large and complex diagrams, Moody (2009, p. 766) suggests that visual notations should provide mechanisms for modularization and hierarchically structuring. Hierarchical structuring of decisions and modularity are a main purpose of DRG. DMN allows the modeler to split up decisions into different tables and specify their connection. DMN leaves it to the implementations of the modeling tool to show interactive visualizations of Decision Requirements Graphs (DRG) in

an efficient way: “For any significant domain of decision-making a DRD representing the complete DRG may be a large and complex diagram. Implementations MAY provide facilities for displaying DRDs which are partial or filtered views of the DRG, e. g., by hiding categories of elements, or hiding or collapsing areas of the network. DMN does not specify how such views should be notated, but whenever information is hidden implementations SHOULD provide a clear visual indication that this is the case” (Object Management Group 2016, p. 35). Decomposition of decisions (splitting decisions into sub-decisions) is relevant for DRDs and well as decision tables, as the number of input variables is visually shown in the DRDs as well as part of the decision tables. Mertens et al. (2015, p. 161) note “The decision table representation also has some drawbacks. When the decisions themselves are based on a very large amount of conditions and actions, the readability of a table gets lost. In such cases, the decision table will need to be split in multiple smaller tables to allow them to stay manageable.” There is a long history of literature on decision table design, offering guidance to structure decisions into separate tables, to build decision tables using a stepwise methodology and to avoid table anomalies and unnormalized tables. For an overview of guidelines for decision table, see e. g. CODASYL Decision Table Task Group (1982). A recent tutorial on using DMN by Signavio for instance suggests to split decisions into sub-decisions as soon as a decision has 7 or more inputs. Overall, decomposition in models can lead to two different effects: despite the positive effect of abstraction, which eases comprehension and has led to the common belief that hierarchically structuring is beneficial for model comprehension, it can also lead to a split-attention effect as readers have to switch between different models or tables (Zugal et al. 2012). Depending on the comprehension task, fully flattened models, respectively decision tables including all input variables may even lead to higher comprehension, as experiments have shown in other modeling domains, e. g. process models (Turetken et al. 2016) or data models (Parsons

2002). While the problem is not new, research for the specific nature of decision modeling is needed. The effects of hierarchical structuring will also differ according to the complexity management and cognitive integration mechanism offered by the modeling tools used. When using table simplification, contraction and normalization, it is also important to consider their effect on repeated use and interactivity of elements; elements that heavily interact cannot be comprehended in isolation and heighten the cognitive load of understanding the decision tables (Sweller 2010). Prior research has demonstrated that different modeling strategies related to minimality and repeated use of elements (e. g. for structuring features in feature trees and using cross-cutting concerns (Reinhartz-Berger et al. 2017)) highly affect model comprehension.

### **Cognitive Integration**

Both, homogeneous and heterogeneous integration are relevant for DMN: heterogeneous integration, because it is important for users to understand the bridge DRDs form to different types of visual representations (especially BPMN diagrams and decision logic tables); homogeneous integration, because more than one diagram of the same type (DRD) can depict a DRG. Although the visualization of DRDs should lower the risk of *hidden dependencies*, which are relationship between components “such that one of them is dependent on the other, but that the dependency is not fully visible” (Green and Petre 1996, p. 153), understanding interconnected decision tables might get hard and should be investigated in empirical studies.

### **Labeling and Naming Conventions**

Labels carry the semantic content. Modeling symbols as decisions, input data or knowledge source as well as input and output columns of the decision tables have to be labeled. For labels of process models, research has already demonstrated that users rate verb-object label styles (e. g. “Determine discount”) for tasks as most useful and least ambiguous (Mendling et al. 2010). Since the top-level decision corresponds to a business rule tasks in a BPMN diagram, a DMN tutorial

(Signavio 2017) recommends to use exactly the same label (in verb-object label style). There are other labeling/naming styles as output style (“Discount”) and question style (“Does the customer get a discount?”) and Signavio (2017) give the following advice: “It is best to use the output style for all other decisions, but in some cases the question style is more intuitive than the output style.” If labels get longer as it is the case in the question style, segmentation and visual design of labels gets more critical (Koschmider et al. 2016). However, empirical research testing the actual effects of naming conventions and visual design of labels are still missing for process models, thus their results cannot be directly transferred to DMN and the specifics of DMN demand a separate empirical evaluation anyway. Addressing this challenge requires future empirical research building on experimental designs.

### **3.3 Research Directions on Organizational Benefits of DMN**

Decisions that are explicitly defined through DMN and not hardcoded inside organizational decision making processes will likely decrease complexity and hence ease the implementation of business rules and analytic technologies. In this way, DMN might contribute to improved efficiency and effectiveness of organizational decision making, e. g. in terms of increased agility (Jonkers et al. 2013), improved business/IT alignment and increased straight-through processing (Taylor et al. 2013). From an organizational point of view, Lemmens (2015) also emphasize the importance of integration of modeling notions, that organizations utilize and develop, namely of process modeling, information modeling and rules modeling, for their organizational goals and operations for agility.

From another perspective, it is also clear that decision execution efficiency is highly affected by the amount of input data that is required to be collected for business process decisions, which is likewise costly for organizations. However, a recent study by Bazhenova and Weske (2017) proposes a method to reduce cost of the input data

collection process through a prioritization algorithm, which might lead to further organizational benefits.

It is also suggested that employing DMN in organizational decision making might be specifically useful in a setting where business rules change frequently and where decisions have high risk for the operations. Hence, sectors like financial services, insurance, energy and ICT providers are listed as recommended areas of use. So far, various processes with strong regulatory requirements in the financial industry are currently redesigned and formalized using DMN. Among others, these include the know-your-customer process, which is subject to regulations for anti-money laundering and counter-terrorist financing rules. Other sectors like health care (Combi et al. 2016; Servadei et al. 2017; Wiemuth et al. 2017), disaster management (Horita et al. 2016), retailers or logistics might benefit in a similar fashion.

On the other hand, as DMN allows separation of control flow and decisions, it may also provide cooperation and can be shared between different stakeholders in Collaborative Networks (Biard et al. 2015) and increase solidly the level of beneficiary gains in organizational goals, settings and outcomes, all of which extends and broadens the limits of research within this domain.

DMN besides, is taking a role in information system development field as well. In the recent example of Boumahdi et al. (2016), DMN is utilized for defining decision view of the service design in SOA, which may be extended to create Model Driven Architectures automatically. In a similar way, it is also emphasized that the use of DMN is considerable with other conceptual models used in information system development phases like requirement specification (Kluza et al. 2017) to improve decision logic definition. Thus, benefits of DMN, in parallel to organizational ones, in system development field and how to incorporate in various phases is another area of research to be explored.

Questions on this organizational level relate to how and in which circumstances, companies

adopting DMN can realize these proclaimed benefits and what success factors play an important role here. Answering these questions requires further research with diverse empirical research methods and cases in this regard.

#### 4 Conclusion

DMN will change the way how processes are specified and implemented. In this paper, we described its technical foundations of decision table research and its theoretical background of modeling research. We identified research directions for investigating its potential benefits on a technological, individual and organizational level, and in this way clarifying what we know and what we don't know about DMN. Insights into the way how programmed decisions are specified and implemented together with business process will be a cornerstone of future research into information systems and business process management in the years to come.

#### References

- Antoniou G., van Harmelen F., Plant R., Vanthienen J. (1998) Verification and validation of knowledge-based systems: Report on two 1997 events. In: *AI Magazine* 19(3), pp. 123–126
- Baesens B., Setiono R., Mues C., Vanthienen J. (2003) Using neural network rule extraction and decision tables for credit-risk evaluation. In: *Management science* 49(3), pp. 312–329
- Batoulis K., Baumgraß A., Herzberg N., Weske M. (2016) Enabling Dynamic Decision Making in Business Processes with DMN. In: Reichert M., Reijers H. A. (eds.) *Business Process Management Workshops 2015. Lecture Notes in Business Information Processing* Vol. 256. Springer, pp. 418–431
- Batoulis K., Haarmann S., Weske M. (2017) Various Notions of Soundness for Decision-Aware Business Processes. In: *ER. Lecture Notes in Computer Science* Vol. 10650. Springer, pp. 403–418

- Bazhenova E. (2017) Optimization of Decision Making in Business Processes. In: Proceedings of the 9th Ph. D. retreat of the HPI Research School on service-oriented systems engineering 100, pp. 9–19
- Bazhenova E., Weske M. (2015) Deriving decision models from process models by enhanced decision mining. In: International Conference on Business Process Management. Springer, pp. 444–457
- Bazhenova E., Weske M. (2017) Optimal acquisition of input data for decision taking in business processes. In: Proceedings of the Symposium on Applied Computing. ACM, pp. 703–710
- Biard T., Mauff A. L., Bigand M., Bourey J. P. (2015) Separation of Decision Modeling from Business Process Modeling Using New "Decision Model and Notation" (DMN) for Automating Operational Decision-Making. In: PRO-VE. IFIP Advances in Information and Communication Technology Vol. 463. Springer, pp. 489–496
- Bock A. (2015) The Concepts of Decision Making: An Analysis of Classical Approaches and Avenues for the Field of Enterprise Modeling In: PoEM Ralyté J., España S., Pastor Ó. (eds.) Vol. 235 Lecture Notes in Business Information Processing Springer, pp. 306–321
- Bossuyt J., Gailly F. (2017) investigating the benefits of modeling business processes with BPMN + DMN. MA thesis, University of Gent, Belgium
- Boumahdi F., Chalal R., Guendouz A., Gasmia K. (2016) SOA<sup>+</sup>: a new way to design the decision in SOA—based on the new standard Decision Model and Notation (DMN). In: Service Oriented Computing and Applications 10(1), pp. 35–53
- Calvanese D., Dumas M., Laurson Ü., Maggi F. M., Montali M., Teinmaa I. (2016) Semantics and Analysis of DMN Decision Tables. In: Rosa M. L., Loos P., Pastor O. (eds.) Business Process Management 2016, Proceedings. Lecture Notes in Computer Science Vol. 9850. Springer, pp. 217–233
- CODASYL Decision Table Task Group (1982) A modern appraisal of decision tables. Association for Computing Machinery
- Combi C., Oliboni B., Zardiniy A., Zerbato F. (2016) Seamless Design of Decision-Intensive Care Pathways. In: 2016 IEEE International Conference on Healthcare Informatics, ICHI 2016, Chicago, IL, USA, October 4-7, 2016. IEEE Computer Society, pp. 35–45
- Dangarska Z., Figl K., Mendling J. (2016) An Explorative Analysis of the Notational Characteristics of the Decision Model and Notation (DMN). In: Dijkman R. M., Pires L. F., Rinderle-Ma S. (eds.) EDOC Workshops 2016. IEEE Computer Society, pp. 1–9
- Ericsson K. A., Lehmann A. C. (1996) Expert and exceptional performance: Evidence of maximal adaptation to task constraints. In: Annual review of psychology 47(1), pp. 273–305
- Figl K. (2017) User Evaluation of Symbols for Core Business Process Modeling Concepts. In: Ramos I., Tuunainen V., Krcmar H. (eds.) 25th European Conference on Information Systems, ECIS 2017, Guimarães, Portugal, June 5-10, 2017, pp. 581–594
- Figl K., Derntl M., Rodriguez M. C., Botturi L. (2010) Cognitive Effectiveness of Visual Instructional Design Languages. In: Journal of Visual Languages & Computing 21(6), pp. 359–373
- Figl K., Laue R. (2015) Influence Factors for Local Comprehensibility of Process Models. In: International Journal of Human-Computer Studies 82, pp. 96–110
- Figl K., Recker J., Mendling J. (2013) A study on the effects of routing symbol design on process model comprehension. In: Decision Support Systems 54(2), pp. 1104–1118
- Gemino A., Wand Y. (2003) Evaluating modeling techniques based on models of learning. In: Communications of the ACM 46(10), pp. 79–84

Genon N., Caire P., Toussaint H., Heymans P., Moody D. L. (2012) Towards a More Semantically Transparent i\* Visual Syntax. In: Regnell B., Damian D. E. (eds.) Requirements Engineering: Foundation for Software Quality - 18th International Working Conference, REFSQ 2012, Essen, Germany, March 19-22, 2012. Proceedings. Lecture Notes in Computer Science Vol. 7195. Springer, pp. 140–146

Genon N., Heymans P., Amyot D. (2011) Analysing the Cognitive Effectiveness of the BPMN 2.0 Visual Notation. In: Malloy B. A., Staab S., van den Brand M. (eds.) Software Language Engineering - Third International Conference, SLE 2010, Eindhoven, The Netherlands, October 12-13, 2010, Revised Selected Papers. Lecture Notes in Computer Science Vol. 6563. Springer, pp. 377–396

Green T., Petre M. (1996) Usability Analysis of Visual Programming Environments: A 'Cognitive Dimensions' Framework. In: Journal of Visual Languages & Computing 7(2), pp. 131–174

Hasic F., De Smedt J., Vanthienen J. (2017) Towards Assessing the Theoretical Complexity of the Decision Model and Notation (DMN). In: Gulden J., Nurcan S., Reinhartz-Berger I., Guedria W., Bera P., Guerreiro S., Fellmann M., Weidlich M. (eds.) Joint Proceedings of the Radar tracks at the 18th International Working Conference on Business Process Modeling, Development and Support (BPMDS), and the 22nd International Working Conference on Evaluation and Modeling Methods for Systems Analysis and Development (EMMSAD), and the 8th International Workshop on Enterprise Modeling and Information Systems Architectures (EMISA). CEUR-WS.org Vol. 1859, pp. 64–71

Hasic F., Devadder L., Dochez M., Hanot J., Smedt J. D., Vanthienen J. (2018) Challenges in Refactoring Processes to Include Decision Modelling. In: Teniente E., Weidlich M. (eds.) Business Process Management Workshops - BPM 2017 International Workshops, Barcelona, Spain, September 10-11, 2017, Revised Papers. Lecture Notes

in Business Information Processing Vol. 308. Springer, pp. 529–541

Hevner A. R., March S. T., Park J., Ram S. (2004) Design science in information systems research. In: MIS quarterly 28(1), pp. 75–105

Hinkelmann K. (2016) Business Process Flexibility and Decision-Aware Modeling - The Knowledge Work Designer. In: Karagiannis D., Mayr H. C., Mylopoulos J. (eds.) Domain-Specific Conceptual Modeling, Concepts, Methods and Tools. Springer, pp. 397–414

Horita F. E. A., Link D., de Albuquerque J. P., Hellingrath B. (2016) oDMN: An Integrated Model to Connect Decision-Making Needs to Emerging Data Sources in Disaster Management. In: Bui T. X., Jr. R. H. S. (eds.) 49th Hawaii International Conference on System Sciences, HICSS 2016, Koloa, HI, USA, January 5-8, 2016. IEEE Computer Society, pp. 2882–2891

Huysmans J., Dejaeger K., Mues C., Vanthienen J., Baesens B. (2011) An empirical evaluation of the comprehensibility of decision table, tree and rule based predictive models. In: Decision Support Systems 51(1), pp. 141–154

Janssens L., Bazhenova E., De Smedt J., Vanthienen J., Denecker M. (2016a) Consistent Integration of Decision (DMN) and Process (BPMN) Models. In: España S., Ivanovic M., Savic M. (eds.) Proceedings of the CAiSE'16 Forum. CEUR Workshop Proceedings Vol. 1612, pp. 121–128

Janssens L., Smedt J. D., Vanthienen J. (2016b) Modeling and Enacting Enterprise Decisions. In: Krogstie J., Mouratidis H., Su J. (eds.) Advanced Information Systems Engineering Workshops - CAiSE 2016 International Workshops, Ljubljana, Slovenia, June 13-17, 2016, Proceedings. Lecture Notes in Business Information Processing Vol. 249. Springer, pp. 169–180

Jonkers H., Quartel D., van den Berg H., Franken H. (2013) Integration of Business Decision Modeling in Organization Design

Kluza K., Wisniewski P., Jobczyk K., Ligeza A., Suchenia A. (2017) Comparison of Selected Modeling Notations for Process, Decision and System Modeling. In: Ganzha M., Maciaszek L. A., Paprzycki M. (eds.), pp. 1095–1098

Koschmider A., Figl K., Schoknecht A. (2016) A Comprehensive Overview of Visual Design of Process Model Element Labels. In: Reichert M., Reijers H. A. (eds.) Business Process Management Workshops - BPM 2015, 13th International Workshops, Innsbruck, Austria, August 31 - September 3, 2015, Revised Papers. Lecture Notes in Business Information Processing Vol. 256. Springer, pp. 571–582

Laurson Ü., Maggi F. M. (2017) A Tool for the Analysis of DMN Decision Tables. In: Azevedo L., Cabanillas C. (eds.) Proceedings of the BPM Demo Track 2016 Co-located with the 14th International Conference on Business Process Management (BPM 2016), Rio de Janeiro, Brazil, September 21, 2016.. CEUR Workshop Proceedings Vol. 1789. CEUR-WS.org, pp. 56–60

Lemmens I. M. C. (2015) Integrating Modelling Disciplines at Conceptual Semantic Level. In: Ciuciu I., Panetto H., Debruyne C., Aubry A., Bollen P., Valencia-García R., Mishra A., Fensel A., Ferri F. (eds.) On the Move to Meaningful Internet Systems: OTM 2015 Workshops - Confederated International Workshops: OTM Academy, OTM Industry Case Studies Program, EI2N, FBM, INBAST, ISDE, META4eS, and MSC 2015, Rhodes, Greece, October 26-30, 2015, Proceedings. Lecture Notes in Computer Science Vol. 9416. Springer, pp. 188–196

Leopold H., Eid-Sabbagh R., Mendling J., Azevedo L. G., Baião F. A. (2013) Detection of naming convention violations in process models for different languages. In: Decision Support Systems 56, pp. 310–325

Lew A. (1978) Optimal conversion of extended-entry decision tables with general cost criteria. In: Communications of the ACM 21(4), pp. 269–279

Mendling J., Reijers H. A., Recker J. (2010) Activity Labeling in Process Modeling: Empirical Insights and Recommendations. In: Information Systems 35(4), pp. 467–482

Mertens S., Gailly F., Poels G. (2015) Enhancing Declarative Process Models with DMN Decision Logic In: Enterprise, Business-Process and Information Systems Modeling: 16th International Conference, BPMDS 2015, 20th International Conference, EMMSAD 2015, Held at CAiSE 2015, Stockholm, Sweden, June 8-9, 2015, Proceedings Gaaloul K., Schmidt R., Nurcan S., Guerreiro S., Ma Q. (eds.) Springer International Publishing, Cham, pp. 151–165

Mertens S., Gailly F., Poels G. (2017) Towards a decision-aware declarative process modeling language for knowledge-intensive processes. In: Expert Systems with Applications 87, pp. 316–334

Moody D. L. (2009) The Physics of Notations: Toward a Scientific Basis for Constructing Visual Notations in Software Engineering. In: IEEE Trans. Software Eng. 35(6), pp. 756–779

Object Management Group (2016) Decision Model and Notation (DMN), Version 1.0. Normative Document

Palmer S. E., Brooks J. L., Nelson R. (2003) When does grouping happen? In: Acta Psychologica 114(3), pp. 311–330

Parsons J. (2002) Effects of Local Versus Global Schema Diagrams on Verification and Communication in Conceptual Data Modeling. In: Journal of Management Information Systems 19(3), pp. 155–183

Petre M. (2006) Cognitive Dimensions "Beyond the Notation". In: Journal of Visual Languages & Computing 17(4), pp. 292–301

Recker J., Rosemann M., Green P. F., Indulska M. (2011) Do Ontological Deficiencies in Modeling Grammars Matter? In: MIS Quarterly 35(1), pp. 57–79

- Reinhartz-Berger I., Figl K., Haugen Ø. (2014) Comprehending Feature Models Expressed in CVL. In: Dingel J., Schulte W., Ramos I., Abrahão S., Insfran E. (eds.) International Conference on Model-Driven Engineering Languages and Systems (MODELS). Springer International Publishing, pp. 501–517
- Reinhartz-Berger I., Figl K., Haugen Ø. (2017) Investigating Styles in Variability Modeling: Hierarchical vs. Constrained Styles. In: Information and Software Technology 87, pp. 81–102
- Schenk K. D., Vitalari N. P., Davis K. S. (1998) Differences between novice and expert systems analysts: What do we know and what do we do? In: Journal of Management Information Systems 15(1), pp. 9–50
- Servadei L., Schmidt R., Bär F. (2017) Artificial Neural Network for Supporting Medical Decision Making: A Decision Model and Notation Approach to Spondylolisthesis and Disk Hernia. In: Ciuciu I., Debruyne C., Panetto H., Weichhart G., Bollen P., Fensel A., Vidal M. (eds.) On the Move to Meaningful Internet Systems: OTM 2016 Workshops - Confederated International Workshops: EI2N, FBM, ICSP, Meta4eS, and OTMA 2016, Rhodes, Greece, October 24–28, 2016, Revised Selected Papers. Lecture Notes in Computer Science Vol. 10034. Springer, pp. 217–227
- Signavio (2017). <https://mooc.house/courses/signavio-%7BDMN%7D-intro>
- Smedt J. D., vanden Broucke S. K. L. M., Obregon J., Kim A., Jung J., Vanthienen J. (2017a) Decision Mining in a Broader Context: An Overview of the Current Landscape and Future Directions. In: Dumas M., Fantinato M. (eds.) Business Process Management Workshops - BPM 2016 International Workshops, Rio de Janeiro, Brazil, September 19, 2016, Revised Papers. Lecture Notes in Business Information Processing Vol. 281, pp. 197–207
- Smedt J. D., Hasic F., vanden Broucke S. K. L. M., Vanthienen J. (2017b) Towards a Holistic Discovery of Decisions in Process-Aware Information Systems. In: Carmona J., Engels G., Kumar A. (eds.) Business Process Management - 15th International Conference, BPM 2017, Barcelona, Spain, September 10–15, 2017, Proceedings. Lecture Notes in Computer Science Vol. 10445. Springer, pp. 183–199
- Subramanian G. H., Nosek J., Raghunathan S. P., Kanitkar S. S. (1992) A comparison of the decision table and tree. In: Communications of the ACM 35(1), pp. 89–94
- Sweller J. (2010) Element Interactivity and Intrinsic, Extraneous, and Germane Cognitive Load. In: Educational Psychology Review 22(2), pp. 123–138
- Taylor J. (2011) Decision management systems: a practical guide to using business rules and predictive analytics. Pearson Education
- Taylor J., Fish A., Vanthienen J., Vincent P. (2013) Emerging Standards in Decision Modeling: An Introduction to Decision Model & Notation. In: iBPMS. Strategies Inc., pp. 133–146
- Turetken O., Rompen T., Vanderfeesten I., Dikici A., van Moll J. (2016) The effect of modularity representation and presentation medium on the understandability of business process models in BPMN. In: International Conference on Business Process Management. Springer, pp. 289–307
- van der Aa H., Leopold H., Batoulis K., Weske M., Reijers H. A. (2016) Integrated Process and Decision Modeling for Data-Driven Processes. In: Reichert M., Reijers H. A. (eds.) Business Process Management Workshops 2015. Lecture Notes in Business Information Processing Vol. 256. Springer, pp. 405–417
- Vanthienen J., Dries E. (1994) Illustration of a decision table tool for specifying and implementing knowledge based systems. In: International Journal on Artificial Intelligence Tools 3(02), pp. 267–288
- Vanthienen J., Mues C., Aerts A. (1998) An illustration of verification and validation in the modelling phase of KBS development. In: Data & Knowledge Engineering 27(3), pp. 337–352

Vanthienen J., Mues C., Wets G. (1997) Inter-Tabular Verification in an Interactive Environment. In: Vanthienen J., van Harmelen F. (eds.) Proceedings of the Fourth European Symposium on the Validation and Verification of Knowledge-Based Systems, EUROVAV'97, June 26-28, 1997, Katholieke Universiteit Leuven, Leuven, Belgium. Katholieke Universiteit Leuven, Belgium, pp. 155–165

Vessey I., Galletta D. F. (1991) Cognitive Fit: An Empirical Study of Information Acquisition. In: Information Systems Research 2(1), pp. 63–84

Vessey I., Weber R. (1986) Structured tools and conditional logic: an empirical investigation. In: Commun. ACM 29(1), pp. 48–57

Wets G., Vanthienen J., Timmermans H. J. P. (1998) Modelling Decision Tables from Data. In: Wu X., Ramamohanarao K., Korb K. B. (eds.) Research and Development in Knowledge Discovery and Data Mining, Second Pacific-Asia Conference, PAKDD-98, Melbourne, Australia, April 15-17, 1998, Proceedings. Lecture Notes in Computer Science Vol. 1394. Springer, pp. 412–413

Wiemuth M., Junger D., Leitritz M., Neumann J., Neumuth T., Burgert O. (2017) Application fields for the new Object Management Group (OMG) Standards Case Management Model and Notation (CMMN) and Decision Management Notation (DMN) in the perioperative field. In: International Journal of Computer Assisted Radiology and Surgery, pp. 1–11

Winn W. (1990) Encoding and retrieval of information in maps and diagrams. In: IEEE Transactions on Professional Communication 33(3), pp. 103–107

Zugal S., Pinggera J., Weber B., Mendling J., Reijers H. A. (2012) Assessing the Impact of Hierarchy on Model Understandability - A Cognitive Perspective. In: Kienzle J. (ed.) Models in Software Engineering - Workshops and Symposia at MODELS 2011, Wellington, New Zealand, October 16-21, 2011, Reports and Revised Selected Papers. Lecture Notes in Computer Science Vol. 7167. Springer, pp. 123–133

This work is licensed under a Creative Commons “Attribution-ShareAlike 4.0 International” license.

