An Explorative Analysis of the Notational Characteristics of the Decision Model and Notation (DMN)

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***Abstract*—Decision models are usually created to complement business process models and to separate them from additional information regarding the decision-making. Like other conceptual models, their purpose is to exceed the representing capabilities of a textual information representation by providing human readers a more visually expressive and cognitively effective form of representation, and if applicable, to allow for future automation. This paper presents findings from a cognitive analysis on the conformity of the newly specified DMN standard notation with principles for effective visual design. While the principle of semiotic clarity and visual expressiveness appeared to be mostly satisfied, visual expressiveness and perceptual discriminability were perceived as partly violated. It was assumed that the DMN notation satisfies the principles of complexity management and cognitive integration. The goal of this first qualitative analysis is to lay the foundation for follow-up, empirical investigations to investigate these ratings.**

I. Introduction

A common expression says that a "picture is worth a thousand words". People often use different kinds of visual expressions such as pictures, icons, diagrams and graphics instead of written text, assuming that this is the more powerful way of presenting information. The relevance of the former saying has also been supported by a vast amount of research on human information processing and cognitive science [1], [2], [3], [4]. Visually represented information is for instance more likely to be remembered due to the "superiority" over printed words [2]. Another advantage of visual information is that it provides a straightforward way to establish communication between experts and novices in a certain domain, as well as between insiders and outsiders to a certain process or organization [5]. This is why *visual notations* have been widely used in software engineering for many years [5]. There are many different visual notations (also called modeling languages) available for different purposes. For example *UML* is an industry standard for specifying software-intensive systems [6], *Petri nets* are used in the areas of model checking, graphically oriented simulation, and software verification [7], *BPMN* is used to model processes [8]. In this paper, the newly specified *DMN* (short for Decision Model and Notation), meant to be used in combination with BPMN or any other business process modeling language, is brought into focus.

A. What is DMN

The DMN notation was designed by the OMG (Object Management Group), which is an open membership, non-profit computer industry standards consortium that produces and maintains computer industry specifications for enterprise applications. In their specification version 1.0, the group describes the purpose of DMN as follows:

> *"The primary goal of DMN is to provide a common notation that is readily understandable by all business users, from the business analysts needing to create initial decision requirements and then more detailed decision models, to the technical developers responsible for automating the decisions in processes, and finally, to the business people who will manage and monitor those decisions."* [9, p.1]

It is supposed to be used together with BPMN [8], [10]. While BPMN (or any other business process model) focuses on the processes themselves, the decisions have to be depicted in separate models, called *Decision Models*. In order to achieve compatibility, business process models have to define tasks within business processes where decision-making is required to occur, then the decision model has to specify in detail the decision-making, carried out in the process tasks. For this purpose the decision modeling is divided into two sub-levels of modeling. Namely these are the *Decision Requirements Level* expressed visually via *Decision Requirements Graphs* or *Diagrams*, and the *Decision Logic Level* captured by *Invocations* or *Decision Tables* (both are also referred to as boxed expressions), allowing them to be associated with elements of a given Decision Requirements Diagram. The role of the Decision Requirements Diagram (DRD) is to define the decisions to be made in a task within the corresponding business processes, their interrelationships, and their requirements for decision logic. The *Decision Logic level* defines the required decisions in sufficient detail to allow validation and (if desired) automation of the decision-making processes. Using decision logic, the components from the DRD are specified in greater detail, to capture a complete set of business rules and calculations. For full automation, the decision logic must be complete, that is, it must be capable of providing a decision result for any possible set of input values. It may also provide

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additional information about how to display elements in the decision model. A special expression language is used for defining decision logic in DMN - *FEEL: the Friendly Enough Expression Language*. Due to the limitations of this paper, the Decision Logic level of DMN is left out of scope.

Three main uses of DMN that can be distinguished: First, it may be used to model human decision-making (including different knowledge sources). The second possible use of DMN is "modeling the requirements for automated decision making" [9, p. 10]. This approach is "similar to modeling human decision-making, except that it is entirely prescriptive, rather than descriptive, and there is more emphasis on the detailed decision logic" [9, p. 11]. After full specification of the decision and business knowledge models using decision logic, the third option for applying DMN in practice can be realized - that is to execute models, which means implementation of automated decision-making by "decision services" or "knowledge maintenance interfaces" [9, p.11].

B. Why is the visual notation of DMN important

The notation of a modeling language can be defined as a set of symbols that visually represent the underlying concepts. The term "decision modeling notation" highlights this visual aspect of the decision modeling language [11]. This visual aspect is meant to increase understanding by analysts and decrease the cognitive load associated with it [2]. The reason for developing DMN is to facilitate decision-making processes and to provide a ground for automating them. This implies that the DMN modeling language should be easily comprehended from all stakeholders - those, who create the model and those, who read and use it. Indeed, this can only be the case when a suitable visual notation is available [11]. Up until now, however, it is unclear how effective the visual notation of DMN truly is.

This paper addresses this research gap. More specifically, we analyze the cognitive effectiveness of the symbol design in the DMN grammar. To this end, we evaluate the elements of the Decision Requirements Graph using principles from cognitive load theory [12], [13], [14], [15] and a theory of effective visual notations [5], guided by previous studies on the effects of symbol design [11], [16]. This will lay the foundation for future empirical tests of the propositions developed in the paper.

We proceed as follows: Section II reviews the literature on cognitive load, cognitive fit and principles for designing effective visual notations. Section III presents the DMN symbol set and evaluates it according to the explained theory. Section IV summarizes the analysis and the limitations of this research.

II. Theoretical background

To allow for an analysis of the DMN's visual notation from a broader perspective, a sound theoretical background is needed. Section II-A discusses cognitive load theory, Section II-B describes the principles of effective visual notations, and Section II-C refers to research on cognitive dimensions.

A. Cognitive load

Every model is created with the purpose of reducing the complexity of a real life's concept to its essential components [10]. Even so, the creation and understanding of models still require high cognitive effort themselves due to the limited information processing capabilities of the human brain. The theory of cognitive load, first developed by John Sweller [12], provides a scientific explanation of these limitations and proposes means of circumventing them. The term cognitive load refers to the total amount of mental effort used in the working memory during the processes of learning and knowledge acquisition. The theory provides evidence for why specific learning designs are efficient.

1) Learning mechanisms: Due to interaction with long-term memory (LTM), the limitations of working memory can be by-passed by coding multiple elements of information as one element in a *cognitive schema* or by *automating rules* [13]. These two learning mechanisms are possible because the long-term memory offers unlimited capacity [13] and provides humans with the ability to vastly expand processing ability [14].

- *Schema construction* helps during the storage and organisation of information in long-term memory, so that it is accessible when and where it is needed. This reduces working memory load. The metaphor of learning the visualisation of a tree demonstrates how schemas work [12]: instead of remembering every leaf and branch separately, only the image of a single tree has to be stored in memory.
- Another learning mechanism that helps by-passing the limited capacity of working memory is the process of *automation*, which affects everything learned, including schemas themselves. For example, "when students first learn to multiply, they may know and understand the rule ..., but they cannot use it without reminding themselves of the mechanics and conditions, under which it is used " [12, p.298]. With time and practice multiplication becomes an automatic action that happens while thinking about some other aspect of the problem.

2) Cognitive load dimensions: Cognitive load theory differentiates between three types of cognitive load [12]: intrinsic, extraneous, and germane. Figure 1 from [17] shows that those three categories are additive in so far that, together, the total load cannot exceed the working memory resources available, if learning is meant to occur [14].

- *Intrinsic cognitive load* relates to the difficulty of the subject matter [12]. A smaller number of elements with a low interactivity is easier than a large number of interactive elements. *Element interactivity* is the driver of intrinsic cognitive load [14]. Material with low interactivity "consists of single, simple, elements that can be learned in isolation, whereas in high interactivity material individual elements can only be well understood in relation to other element" [15, p. 106]. Also factors such as content difficulty, change of ontological categories and

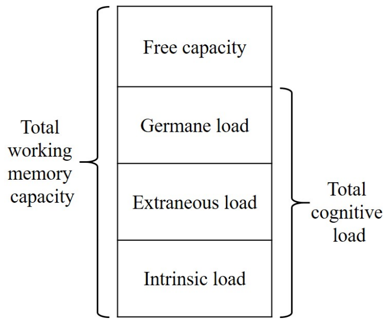


Fig. 1. Cognitive load and total working memory capacity [17]

specific characteristics of the relations between elements can influence intrinsic cognitive load. Intrinsic cognitive load is regarded as constant. That means it cannot be changed by characteristics of the instructional material, although some researchers disagree with this statement [18], [19].

- *Extraneous cognitive load* is additional cognitive load that is caused by the presentation of the material and "that does not directly contribute to learning (schema construction)" [15, p. 108]. Different types of representation can impact the relative difficulty of a task, which can depend on a number of factors. The "*split-attention*" effect for instance, refers to the separate presentation of domain elements that require simultaneous processing. This can be remedied by presenting material in an integrated way [15]. A second source of extraneous cognitive load identified by Sweller [12] is when one must solve problems for which there is *no previous schema-based knowledge*. Another important finding of cognitive load research is the *modality principle*, which implies that information is more efficiently presented as a combination of visual and auditory material. Addressing only one part of the working memory (only audition or only vision) may lead to a less efficient information processing [12]. In addition, the *redundancy effect* is also worth mentioning, as it consumes more cognitive resources than necessary by coordinating multiple materials having the same information, when in fact only one of them would be enough. In general, extraneous cognitive load should be kept low, however as the analysis in [15] shows, it is not always evident which characteristics of material can be regarded as being extraneous. Paas, Renkl and Sweller state that "extraneous cognitive load is primarily important when intrinsic cognitive load is high because the two forms of cognitive load are additive. If intrinsic cognitive load is low, levels of extraneous cognitive load may be less important because total cognitive load may not exceed working memory capacity." [14, p.2].
- *Germane cognitive load* is imposed by the processes involved in the construction of schemas, such as interpreting, exemplifying, classifying, inferring, differentiating, and organizing. While other types of cognitive load should be kept low, germane cognitive load enhances learning, which indicates that maximum capacity should be available for this kind of cognitive load. [14].

Source of Cognitive Load		Influence Factors on Cognitive Load
Notational design level	Symbol	Semiotic clarity, visual expressiveness, semantic transparency
	Symbol set	Graphic economy, perceptual discriminability, visual expressiveness, semiotic clarity
	Primary notation	Graphic economy, dual coding, cognitive fit, complexity management, cognitive integration
Model level	Secondary notation	Model layout (edge crossings, modularity), textual labels
	Inherent factors	Size, density, structuredness, structure, complexity

Fig. 2. Factors influencing cognitive load involved with model comprehension adapted from [16]

3) Cognitive load and model comprehension: For the purposes of this paper, a connection has to be established between the theory of cognitive load and the subject of model comprehension. To give an overview of what factors could influence cognitive load involved in model understanding, Figl et al. propose a table, as shown in Figure 2, with a focus on notational aspects [16]. Their analysis distinguishes between two levels of extraneous cognitive load - *notational design level* and *model level*. On the notational design level, cognitive load can be influenced by factors regarding each symbol, a symbol set or the formal use of a modeling grammar - the so called primary notation [16]. The associated factors with secondary notation, such as model layout, and other inherent factors, such as model size and complexity relate to the sources of extraneous cognitive load on the model level.

B. Principles for designing effective visual notations

In order to adequately evaluate the visual notation of DMN, a suitable scientific basis is needed. Therefore, we refer to the set of nine principles for designing effective visual notations defined by Moody in [5].

Moody recognizes a gap in previous literature, concerning the visual syntax of software engineering modeling languages and criticizes the way it has been undervalued, channeling the focus on discussing language semantics. His theory directs attention to the optimal form in which information should be presented to the human brain, so that both human understanding and problem solving capabilities are increased. For this purpose, he proposes nine base principles.

1) Principle of semiotic clarity: The first principle proposed by Moody states that every symbol in a given notation has to represent only one concept. This constraint is needed to maximize precision, expressiveness and parsimony, which are "desirable design goals for SE notations" [5, p. 761]. There are four different ways to violate this rule. First, *symbol redundancy*, which occurs when symbol A, as well as symbol B can represent the same construct. This impairs the choice of the notation's user, rather than his memory capacity. Next, *symbol overload* occurs when construct X and construct Y can be represented by the same symbol. This anomaly leads to ambiguity and potential misinterpretation, hence, according to Moody, it is the worst type of anomaly. The last two possible violations of semiotic clarity are *symbol excess*, which occurs when there is no corresponding semantic construct for a given symbol, and *symbol deficit*, which emphasizes the opposite phenomenon. All these anomalies should be considered when analyzing a notation, thereby the last one is sometimes desirable to limit diagrammatic and graphic complexity [5].

2) Principle of perceptual discriminability: The second principle emphasizes that different symbols should be clearly distinguishable from each other in order to stimulate faster and more accurate symbol recognition. Satisfying this principle is especially important, because accurate discrimination between symbols is a prerequisite for accurate interpretation of diagrams [20]. To ensure better discriminability between symbols, one has to consider a greater visual distance - that is the case if there are more visual variables, on which symbols differ. Thereby, it is important to take into account that shape is the primary visual variable for distinguishing objects, but also other features are involved. Shape has indeed unlimited capacity of values and is by far the most used object feature [21]. Even so, most software engineering notations use only a limited range of shapes (mostly rectangle variations). Techniques, such as *redundant coding* (using multiple visual variables [22]) and *perceptional pop out* (introducing elements with unique values for at least one visual variable [23]), are suggested by Moody to make use of shape, color, size and text in combination, so as to maximize discriminability between different elements in a notation. He stresses the crucial point [5, p. 764]: "Text is an effective way to distinguish between symbol instances, but not between symbol types."

3) Principle of semantic transparency: The third principle prescribes the use of symbols, whose appearance suggest their meaning. The aim is to provoke intuitive associations, so as to lower the cognitive load needed to comprehend a model. A good cue in this case is *iconic representation*, since icons "perceptually resemble the concepts they represent"[5, p. 764]. A everyday example of an intuitive icon is the stick man, commonly used to represent a person in various communications and diagrams. Using this technique, a given representation becomes less ambiguous in comparison with one, composed of abstract symbols only. Another aspect of semantic transparency are the relationships among visual elements in a model. Moody states that certain spatial arrangements suggest particular interpretations [20], like for example the notion that an element on the left side of a diagram precedes the one on the right.

In line with this principle other research on symbol characteristics [24] lists concreteness, visual complexity, meaningfulness, semantic distance, and familiarity to be of central importance. The findings of McDougall et al. [24] suggest that concrete symbols with a detailed, complex representation are more visually obvious and meaningful than abstract symbols. The term *semantic distance* stands for the closeness of the relationship between the symbol and its intended meaning. The goal must be to keep this distance as short as possible. If, however, the relationship between symbol representation and its meaning is weaker, it is the *familiarity* with this symbol that allows for interpretation. Familiarity reflects the frequency, with which symbols are encountered. The effects of some symbol characteristics on performance, such as color and concreteness, diminish as symbols become more familiar but others, such as complexity, do not [24]. All these symbol properties are thought to be important determinants of semantic transparency.

4) Principle of complexity management: This principle addresses one of the known and most important problems with visual notations, and that is that they "do not scale well" [25]. Complexity has a major effect on cognitive efficiency, as there are perceptional limits, as well as cognitive limits in comprehending a diagram. According to [5], one's ability to discriminate between elements is affected by the size of the diagram. In addition, the number of elements that can be comprehended at a time is limited by working-memory [3]. Hence, to avoid cognitive overload, Moody proposes two techniques for dealing with complexity: *modularisation*, which aims at decomposing and dividing bigger models into smaller parts that are more easily manageable by human's perceptional and cognitive capacities, and *hierarchical structuring*, which deals with organizing different levels of abstraction with complexity manageable at each level. The principle of *recursive decomposition* supports both mechanisms and is commonly used among notations that effectively manage complexity [26].

5) Principle of cognitive integration: The next principle applies only when different diagrams are used to represent a system. There is a range of mechanisms facilitating the cognitive integration of diagrams. The term *conceptual integration* comprises methods aimed at helping the reader to assemble information from separate diagrams. One such method is the *summary diagram* (also called *longshot* diagram), which provides a view of the system as a whole. Another way to integrate multiple concepts is *contextualization* to display where a part is positioned in the context of the whole system. The term perceptual integration on the other hand, provides cues to simplify navigation and transition between diagrams, like orientation, route choice, route monitoring and destination recognition. Moody believes that "no existing notations fully satisfy this principle"[5, p. 767].

6) Principle of visual expressiveness: Moody's sixth principle for designing effective visual notations recommends the use of all visual variables when depicting a symbol in order to increase its information capacities. According to his opinion, shape is one of the least powerful visual variables and is one of the least cognitive efficient [27], regardless of its primacy effect. Conversely, color is the most cognitive effective, as differences in color are detected three times faster than shape and are also easier to remember [28]. However, Moody suggests that color should only be used for redundant coding to ensure a robust design. Also important is the choice of visual variables. This choice should be based on the information to be conveyed [29]. In general, to satisfy this principle, one should aim to match the properties of visual variables with the properties of the information they represent, and graphic encoding should be preferred over textual encoding.

7) Principle of dual coding: This principle stands for using text to complement graphics, which, as per dual coding theory [30], is more effective than using either of them on their own. For example, the use of *annotation* in terms of textual explanations may improve understanding, because displaying them on the diagram is much more effective than including them in a separate document (as it is commonly done in practice) [31]. Alternatively *hybrid representation* (graphic + text) may aid interpretation by simultaneously expanding and reinforcing the meaning of the graphics [5]. It has to be noted, that dual coding does not affect discriminability. However, interpretation is improved in the case of symbols with low semantic transparency, and retention is improved by interlinking visual and verbal encoding in memory [5].

8) Principle of graphic economy: This principle relates to the principle of complexity management. It emphasizes that the number of different elements in a diagram should be adjusted in accordance with human‘s limited ability to discriminate between alternatives. Three strategies are most important for dealing with excessive graphic complexity, as per Moody‘s theory: *reduce semantic complexity*, *introduce symbol deficit*, and *increase visual expressiveness*. Reducing the number of semantic constructs in a notation leads respectively to reduction of graphic complexity as well. Symbol deficit can also remedy this problem by "choosing not to show some constructs graphically" [5, p. 70]. The last strategy aims to increase human discrimination ability by increasing the number of perceptual dimensions, on which stimuli differ, as opposed to reducing complexity.

9) Principle of cognitive fit: This principle rests on the theory that different representations of information are suitable for different tasks and different audiences. Vessey [4] states that if the problem representation and the problem solving task "fit", then a mental representation is formulated that leads to effective and efficient problem-solving performance. Vessey [4] has performed experiments of the effects of graphical and tabular representations on decision-making performance to propose the theory of cognitive fit. She views problem solving as an outcome of the relationship between problem representation and problem solving task. When the same type of information is emphasized in both problem-solving elements (representation and task), the problem solver uses processes, which also match the given type of information (similar processes to act on the representation and to complete the task). For example, if a trend is to be extracted from a data set, the most suitable representation form for completing such task would be the graphical (also called spatial), as it allows multiple data points to be examined simultaneously.

In the context of conceptual modeling, expert-novice differences depend on the problem-solving skills of the target group and the representational medium. A basic distinction is for instance hand-written vs. computer-based drawing [5]. A main problem is satisfying all relevant target groups. A possible solution according to Moody is considering "pro" versions, to be used by experts, and "lite" versions, to be used by novices. In terms of representational medium, the use of two separate dialects is suggested: a simplified notation for sketching and a more enriched notation for final diagrams [5].

C. Principles for designing effective visual models

All notational factors influencing extraneous cognitive load have been discussed above. Important is also the concept of secondary notation. The term *secondary notation* stands for the way a specific model is visualized. Petre states that "*good graphics* usually means linking perceptual cues to important information", and is concerned with the fact that this "major determinant of 'good' graphics is not part of the formal system" [21, p. 35]. This means that secondary notation goes beyond what is defined by the formal specification of a modeling notation. For instance, an appropriate grammatical style of the textual labels, the chosen grade of modularity, and color highlighting can be applied in a way that will aid model understanding. Indeed, such modifications are often discussed in conceptual modeling research [32], [33].

Conversely, the study of Petre [21] demonstrates that using poor secondary notation is not merely neutral, but can also be confusing and misleading. Examples of such bad usage are grouping elements visually that are not related logically, dispersing related elements or using symmetry or highlighting arbitrarily. Such layout-related effects are also found in other studies [34].

Because the factors on the model-level depend on the personal style, and the individual skills differ from case to case, an a priori analysis of DMN's secondary notation is not possible. However, useful guidelines for meeting the quality requirements for a "good" DRD can be formulated based on research into modeling languages and graph aesthetics. Layout-related effects are investigated, among others, in research by Purchase [34]. Her work on graph drawing suggests "the most effective aesthetics to use from the point of view of human reading of relational information" [35]. The results of on of her studies have indicated that *line crossing* is the most important aesthetic, and thus, it is proposed to minimize the number of crossings in a graph to increase understandability. In the context of DMN, one should avoid crossing the lines of the requirements used to connect the DRD elements. The other suggestions of Purchase's study for improving model understanding are listed in decreasing importance according to the strength of their impact:

- Minimizing the number of *edge bends*. This finding advises the use of straight lines as opposed to bent ones, whenever possible.
- Maximizing perceptual *symmetry* is a useful tip, but only when applied in accordance with the decision model's logic.
- Maximizing the *orthogonal structure* - that is fixing nodes and edges to an orthogonal grid.
- Maximizing the minimum *angles* between edges leaving a node.

These rules can be further extended by the *use of locality* as proposed by [36]. This rule suggests that graphical elements, which are related to each other (for instance a Decision element and all its Input Data elements), should be placed close to each other, and by *consistent labeling* [37], [38], using, for example, only nouns to label the decision elements. In addition, as stated in [10] a diagram with more than 30 elements is not easily comprehensible, so it would be advisable to limit the *size* of a DRD.

III. DMN Analyses

In this section an analysis of the symbol set of DMN is provided and propositions about its visual effectiveness are stated. Moody's "physics of notations" [5] serves as a framework for the analysis. The emphasis is put on the principles of semiotic clarity, visual expressiveness, semantic transparency and perceptual discriminability. Also, the principles of dual coding, complexity management, cognitive integration and cognitive fit are addressed, but in less detail. Section III-A summarizes the major notational elements of a Decision Requirements Graph (DRG). Section III-B analyzes the symbols separately and Section III-C considers the symbol set altogether.

A. The Decision Requirements Diagram of DMN

The scope of this paper is limited to the *Decision Requirements Level* of the DMN notation, due to its diagrammatic nature. It is the more abstract level of modeling, composed of a Decision Requirements Graph (DRG), and represented in one or more Decision Requirements Diagrams (DRD). A DRG models a domain of decision-making, showing its most important elements and the dependencies between them. This includes the decision and its immediate sources of information, knowledge, and authority are present in the same graph [9]. On the other hand, a DRD is only presenting a partial or filtered view of a DRG. The DMN specification does not specify the contents of a DRD, however where information is not shown, the application used for modeling should provide a clear visual indication that this is the case.

Tables I and II (adapted from [9]) illustrate and shortly describe the meaning and usage of the seven notational symbols as used in the decision requirements level of DMN. By connecting them and complying with certain connection rules specified in [9], one can build either a *Decision Requirements Graph* or a *Decision Requirements Diagram*.

The rules governing the permissible ways of connecting elements with requirements in a DRG/DRD are summarized in the following list:

- The arrows are drawn in the direction of the information flow. That is towards the element requiring the corresponding information or knowledge or from the source of authority to the element governed by it.
- Information Requirements can be used only to connect two Decisions or to connect an Input Data to a Decision.
- Business Knowledge Models may be invoked by multiple Decisions or other Business Knowledge Models.
- Knowledge Requirements may be drawn from Business Knowledge Models to Decisions, and from Business Knowledge Models to other Business Knowledge Models.
- Knowledge Sources may provide authority for multiple Decisions and/or Business Knowledge Models.
- No requirements may be drawn terminating in Input Data, that is Input Data may have no requirements.
- Authority Requirements may be used in two ways:
  1) They may be drawn from Knowledge Sources to Decisions, Business Knowledge Models, and other Knowledge Sources, where they represent the dependence of the DRD element on the Knowledge Source in focus.
  2) They may be drawn from Input Data and Decisions to Knowledge Sources, where, in conjunction with the former use, they represent the derivation of Business Knowledge Models from instances of Input Data and Decision results.

Figure 3 illustrates these rules of the permissible connections by showing a simple DRD adapted from the specification [9].

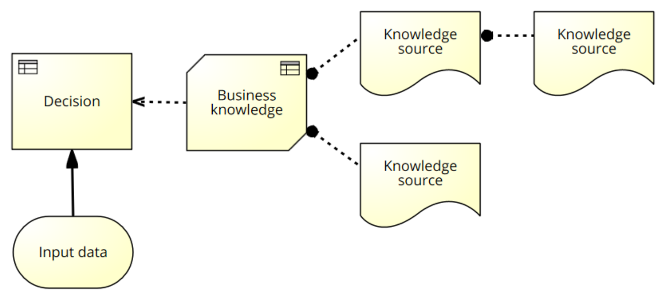


Fig. 3. Simple example of the permissible connections in a DRG [9]

B. DMN Symbol Analysis

As discussed in relation to cognitive theory above, the factors influencing cognitive load on the symbol-level are semiotic clarity, visual expressiveness and semantic transparency. The symbols and their descriptions in Tables I and II allow the discussion of their *semiotic clarity*. Each of the shown elements denotes a different concept and corresponds to one semantic construct. In general, there is no strict violation of this principle, although in the case of Knowledge Source elements and Authority requirements it may be spoken of symbol overload. This is because all kinds of knowledge sources (human sources, sources in paper form, digital sources or other) are represented by the same symbol. Similarly, an authority requirement can be used to depict two different kinds of dependencies. Hence the principle of semiotic clarity is not fully satisfied by DMN.

The next question to be answered is whether the symbols are *visually expressive* and to what extent. Moody [5] proposes a scale from zero to eight for measuring this property. A non-visual (or textual) symbol uses zero visual variables, while a visually saturated symbol uses all eight - horizontal

TABLE I
ELEMENTS OF A DECISION REQUIREMENTS GRAPH OR DIAGRAM

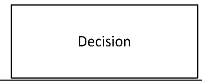
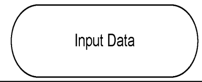
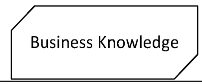
Component	Description	Notation
Decision	Denotes the act of determining an output from a number of inputs, using decision logic which may reference one or more business knowledge models.	
Input Data	Denotes information used as an input by one or more decisions. When enclosed within a knowledge model, it denotes the parameters to the knowledge model.	
Business Knowledge Model	Denotes a function encapsulating business knowledge (e.g., as business rules, a decision table, or an analytic model).	
Knowledge Source	Denotes an authority for a business knowledge model or decision.	

TABLE II
REQUIREMENTS OF A DECISION REQUIREMENTS GRAPH

Component	Description	Notation
Information Requirement	Denotes input data or a decision output being used as one of the inputs of a decision.	
Knowledge Requirement	Denotes the invocation of a business knowledge model.	
Authority Requirement	Denotes the dependence of a DRD element on another DRD element that acts as a source of guidance or knowledge.	

position, vertical position, size, brightness, color, texture, shape, orientation. Based on this scale DMN symbols are only one-dimensional, as shape is the only applied variable. All elements are similarly positioned, oriented and sized. This suggests, that the DMN notation is weak in terms of visual expressiveness. For the requirements concept, they use a second visual variable: texture. As per the DMN specification, it is up to the modeling applications to decide if they want to include color or brightness as additional visual variables.

Finally, the symbols are evaluated according to their *semantic transparency*. As claimed by Moody [5], semantic transparency is not a binary state but a continuum between semantically immediate symbols (such as a stick figure referring to a person) and semantically perverse symbols (one is likely to infer a different meaning from their appearance). In the neutral middle, there are the semantically opaque symbols, where the relationship between them and their appearance is purely arbitrary. In conformity with the proposed scale, the elements from the DMN notation can be placed onto the zero point. Specifically, none of the symbols provides a cue to its meaning, and thus they cannot be regarded as natural or intuitive. On the other hand, the Information requirements and Knowledge requirements do represent semantically transparent relationships, as their arrowheads point in the direction of the information/knowledge flow. Authority requirements, by contrast, require some initial explanation for understanding the dependency type meant by the symbol, and in the same time to prevent one from making a wrong inference, which places them rather on the semantically perverse side.

C. DMN Symbol Set Analysis

What follows, is an exploration of DMN's symbol set. For our analysis, we consider the symbol set comprising of the whole primary notation as proposed by the specification of DMN. In addition to semiotic clarity and visual expressiveness, which also apply to the symbol-analysis, there are the criteria graphic economy, perceptual discriminability, dual coding, cognitive fit, complexity management and cognitive integration which need to be discussed subsequently.

Unlike visual expressiveness, which acts across the entire visual vocabulary, *perceptional discriminability* measures "pairwise visual variation between symbols" [5]. The goal is to have symbols that are clearly distinguishable from each other by providing sufficient visual distance between them. When observing each DMN symbol separately, they seem completely different and unique. However, placed together in a model, they are not so easy to differ.

The similarities between the four notational elements are rooted in the limited repertoire of shapes used. That is all of them are built around the rectangle shape. For example the Decision element, represented by a simple rectangle, and the Knowledge Source element differ only by the down side, which in the later case is wavy. Likewise, Business Knowledge Model and Decision are only distinguishable by the two clipped corners of the former. The visual representation of Input Data is slightly more divergent with its two parallel straight sides and two semi-circular ends, but still the visual distance is short, due to encoding information only through the shape variable. To remedy this deficiency, some modeling tools, like ADOxx for instance, introduce coloring to improve the perceptional discriminability between DMN elements.

Unfortunately, there are no proposed alternatives for the visually similar representations of the requirements. While the solid line and the solid arrowhead of the Information Requirement are likely to "pop out", the Knowledge Requirement and the Authority Requirement, which are both drawn with a dashed line, differ only in the shape of their arrowhead. One possible solution according to Moody's theory is *dual coding* or complementing the graphics with text; however, DMN does not support this feature. In contrast, the notation has already made use of dual coding by listing the properties of a Decision beneath the Decision's label, separated with a horizontal line. The element-labels themselves are also a form of dual coding, without which a DRD would be completely incomprehensible, if not meaningless.

Increasing visual expressiveness and adopting dual coding are both in harmony with the principle of *graphic economy*, which demands a reasonable balance between the expressiveness of a notation and the number of its symbols [11]. Since DMN, on its Decision Requirements level, is not as complex as other notations, such as UML for instance, an assumption can be made that further simplification of the semantics is not necessary. With size, however, diagrammatic complexity increases. Fortunately, DMN accommodates methods for *complexity management*. For this purpose, large Decision Requirements Diagrams may be divided into smaller, easily comprehensible ones. It is again left to the model tool implementations to provide options for displaying DRDs, which are partial or filtered views of an overall DRD or a DRG. Decision Requirements Graphs in turn are perfect examples of the *cognitive integration* property, which seems to be fully satisfied by DMN.

Last, the *cognitive fit* of the notation is addressed. According to cognitive fit theory, a diagram in general is an appropriate way to facilitate the decision-making process. So far, this indicates a good cognitive fit of DMN. On the other hand, the lack of different visual dialects for different audiences (experts versus novices) and different representational media (hand-written versus computer-based) suggests otherwise [5]. As a consequence, the question regarding this last influence factor remains open.

D. Summary of the Analyses

Based on the number and types of issues identified above we can hypothesize about cognitive effectiveness of different symbols of the DMN. In Table III we conceptualize our analysis above by highlighting relatively good ("+"), average ("+/-") and weak support ("-") of cognitive effectiveness of the symbols considered.

IV. Conclusion

In this paper, we have discussed the recent DMN specification from the perspective of its visual notation. As visual notations form an integral part of modeling languages [5], their effectiveness is highly important for the practical application and usage. DMN is a recent standard and its visual effectiveness has not been investigated so far. The work reported in this paper addresses this research gap. To this end, we have applied cognitive load theory [12], [14], [15], the theory of cognitive fit [4], and the principles of visual notational design [5]. Our contribution is an analysis of the effectiveness of the DMN notation according to the principles formulated by Moody. As a result of this analysis we find room for improving visual expressiveness and perceptional dicriminability of DMN. Also, deficiencies in terms of semiotic clarity of the Knowledge Source element and the Authority requirement are identified. In addition, all DMN symbols, with the exception of the Information and Knowledge requirements exhibit relatively low semantic transparency. Also strengths were found. DMN seems to be fully capable of managing complexity, as it allows to decompose large DRDs and DRGs into smaller, more comprehensible ones. Also, the principle of cognitive integration appears to be satisfied, merely due to the existence of DRGs. The authors of this work argue that no further simplification of the grammar is needed.

A limitation of this work is that the logic level of DMN is left out of scope. Further research is required to address this level of the notation. For instance, an analysis of the Decision table and the Boxed invocations may be conducted based on cognitive fit theory. The results reported in this paper represent propositions that require empirical validation. In future research, we plan to carry out experiments to examine the validity of these propositions. Still, this paper is unique as it is the first one to provide a systematic analysis of DMN from a cognitive point of view.

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TABLE III
RELATIVE STRENGTHS AND WEAKNESS OF SYMBOLS FOR REQUIREMENTS

	Decision	Input Data	Business Knowledge Model	Knowledge Source	Information Requirement	Knowledge Requirement	Authority Requirement
Semiotic Clarity	+	+	+	- (overloaded)	+	+	+/- (overloaded)
Visual Expressiveness (scale from 1 [low] to 8 [high] visual variables used)	1	1	1	1	2	2	2
Semantic Transparency (scale from -1 [perverse] to 0 [opaque] to +1 [immediate])	0	0	0	0	+1	+1	-1
Perceptual Discriminability	-	+/-	-	-	+	-	-

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