A DMN-Based Method for Context-Aware Business Process Modeling Towards Process Variability

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Abstract. Business process modeling traditionally has not paid much attention to the interactive features considering the dynamism of the environment in which a business process is embedded. As context-awareness is accommodated in business process modeling, decisions are still considered within business processes in a traditional way. Moreover, context-aware business process modeling excessively relies on expert knowledge, due to a lack of a methodological way to guide its whole procedure. Lately, BPM (Business Process Management) is moving towards the separation of concerns paradigm by externalizing the decisions from the process flow. Most notably, the introduction of DMN (Decision Model and Notation) standard provides a solution and technique to model decisions and the process separately but consistently integrated. The DMN technique supports the ability to extract and operationalize value from data analytics since the value of data analytics lies in improving decision-making. In this paper, a DMN-based method is proposed for the separate consideration of decisions and business processes, which allows to model context into decisions as context-aware business process models for achieving business process variability. Using this method, the role of analytics in improving some part of the decision making can also be integrated in the context-aware business process modeling, which increases the potential for using big data and analytics to improve decision-making. Moreover, a formal presentation of DMN is extended with the context concept to set the theoretical foundation for the proposed DMN-based method.

Keywords: Decision modeling · Context-aware business process · Process modeling · Process variability

The original version of this chapter was revised: A link to reference 12 has been added in two places. The correction to this chapter is available at https://doi.org/10.1007/978-3-030-20485-3_42

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W. Abramowicz and R. Corchuelo (Eds.): BIS 2019, LNBIP 353, pp. 176–188, 2019.
https://doi.org/10.1007/978-3-030-20485-3_14

1 Introduction

A business process model captures a set of logically related tasks to achieve a particular goal. BPM (Business Process Management) continues receiving significant attention, and building business processes accommodated to dynamic context is considered as a major challenge. Recent studies have explored context-awareness as a new paradigm and principle in designing and managing a business process [1, 2]. In order to model a context-aware business process towards variability, relevant contextual data needs to be integrated in a traditional process model as a key aspect of its data perspective, and its consequential process variants need to be modeled as well. Then the research question can be presented as "*What data constitutes the context of a business process and how does the context lead to business process variability?*".

Some researchers have attempted to answer this research question by proposing methods to organize different adaptation variants in a business process model, such as methods based on process invariants [3], context-based process variants [4], adaptation components [5] and instance fragments [6]. Nevertheless, relevant contextual data and resulting process variants, i.e., process fragments that possibly occur, have been determined according to expert knowledge. There is a lack of a methodological method to determine relevant data that constitutes the context of a business process and to bridge the gap between the dynamic context and consequent process variants.

Lately, BPM is moving towards the separation of concerns paradigm by externalizing decisions from the process flow. Most notably, the introduction of DMN (Decision Model and Notation) standard [7], provides a solution and technique to model decisions and the process separately but consistently integrated. Moving towards the context-aware BPM, decisions has been still considered within business processes in a traditional way, which impairs the maintainability, scalability, and flexibility of both processes and decisions, as well as the analytics capability of business processes. In this paper, a DMN-based method for context-aware business process modeling is proposed to provide a systematic solution of the research question, which allows to model context into decisions to achieve process variability.

2 Motivation and Related Work on Context-Aware Business Process Modeling

Up to date, many researchers have realized that context is vital to agile BPM and have paid attention to the content and characteristics of context-aware business processes [1, 8], approaches to model context-aware business processes [9–11], tools for supporting the integration of contextual data and business processes [12] and some prototype cases were presented as well. In particular, a number of research efforts have been undertaken to integrate contextual elements for extending the traditional notion of a business process to pursue flexible business processes [13]. Process flexibility is referred to as the capability to cope with externally triggered changes by modifying only parts of a business process instead of replacing it [14], without losing its "identity" [3]. Capturing variability in business process models can provide process flexibility. Typically, for a

particular process type, a multitude of process variants exists, each of them being valid in a particular context [15]. Moreover, the context of a business process is identified as the extrinsic driver for process flexibility [14], which needs to be considered in the process modeling towards variability in BPM.

Moreover, Since the early 1960s, the context concept has been modeled and exploited in many areas of informatics [16]. Many researchers have tried to define the context concept in their own work. Context seems to be a slippery concept, which keeps to the periphery, and slips away when one attempts to define it [17]. Researchers understand context and the context of a business process in different ways according to their background. Consequently, context-aware process modeling relies on expert knowledge excessively, due to a lack of a methodological way to guide the whole procedure of context-aware business process modeling.

Context-aware business processes gather contextual information of a user and a business process and adapt their behavior accordingly [4]. A workaround that is often observed in modeling practices of a context-aware business process is that a contextual variable becomes an explicit condition of control flow leading to a decision point such as "check if the process occurs in the holidays". Moreover, rule-based approaches are commonly used for automating decision making to enable a business process to be aware of context since rules usually derivate from dynamic changes of context [9]. However, decisions are still considered within context-aware business process modeling, which impairs the capability of decisions on context-aware BPM. Hence, in this paper, decision modeling is utilized for modeling the context-aware business process in a methodological way with less reliance on experts.

3 DMN Modeling Technique

DMN is designed as a declarative decision language to model the decision dimension of a business process, which consists of two levels that are to be used in conjunction [7]. Figure 1 depicts key elements involved in the DMN Technique. One is the decision requirements level, represented by the DRD (Decision Requirements Diagram), which depicts requirements and dependencies between data and sub-decisions involved in the decision model. Figure 4 depicts an example of a DRD. These input data can be static or dynamic, which may be extracted directly from databases, sensors and IoT devices, or generated by data fusion, data analytics and machine learning. The other one is the decision logic level, presented by the Business Knowledge Model (BKM), which encapsulates business know-how in the form of decision rules or a decision table. Figure 5 is an example of the decision logic presentation. BKMs origin from some knowledge sources of authorities that can be guidelines, regulations or analytics systems. Analytics capability is therefore able to be integrated to improve the decision-making of a business process.

Organizations are increasingly investing in data-driven analytics to improve their business results, deepen customer understanding and better manage risk. The value of these analytics lies in improving decision-making. In other words, unless a decision is improved as a result of analytics it is hard to argue that the analytics have any value [18]. Explicit decisions from a business process can improve using analytics. If decisions are

identified, modeled and understood, the potential for analytics to improve it would be much clearer. Data analytics can be used to add support for BKMs or data requirements of decisions. More specifically, outcomes of data analytics can be provided as parameters of decision logic (i.e., decision tables or decision rules) or data inputs for decision models. The DMN technique provides an effective solution for the separate consideration of the decision dimension from a business process and supports the ability to extract and operationalize value from data analytics.

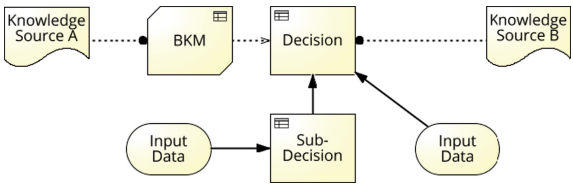


Fig. 1. Key elements of the DMN technique.

4 DMN Formal Presentation Extended with the Context Concept

We adopt the formal presentation of DMN constructs provided in [19] and extend it with sub-decisions and contextual data as the theoretical preliminaries of the proposed DMN-based method for modeling context-aware business processes.

In the DMN constructs, a decision in a business process can be formally defined as follows:

A decision in a process model, $d^a \in D_{dm}$ is a tuple (I_{da}, O_{da}, L_{da}), where $a \subseteq A_d$, $I_{da} \subseteq I(a)$, $O_{da} \subseteq O(a)$, and $L_{da} \subseteq L$.

The symbols in the formal presentation of a decision in a business process:

- d^a refers to a decision of decision type activities in a business process.
- D_{dm} refers to a finite non-empty set of decision nodes of a DRD, and an example is depicted in Fig. 4. DRD is a tuple (D_{dm}, ID, IR), consisting of decision nodes D_{dm}, a finite non-empty set of input data nodes ID, and a finite non-empty set of directed edges IR representing the information requirements such that $IR \subseteq (D_{dm} \cup ID) \times D_{dm}$, and $(D_{dm} \cup ID, IR)$ is a directed acyclic graph (DAG).
- $d^a \in D_{dm}$ is a tuple (I_{da}, O_{da}, L_{da}), presents that a decision d^a is one of decision nodes in a DRD D_{dm}, where $I_{da} \subseteq ID$ is a set of input symbols, O is a set of output symbols, and L is the decision logic defining the relation between symbols in I_{da} and symbols in O_{da}.
- A refers to a finite non-empty set of activities in a business process and $A_o \cup A_a \cup A_d = A$, where A_o is a finite non-empty set of operational activities ((no) inputs, no outputs), A_a is a finite non-empty set of administrative activities (no inputs, outputs), and A_d is a finite non-empty set of decision activities (inputs, outputs), which serve a decision purpose by transforming inputs into an outcome.

- $a \subseteq A_d$ presents that a is a type of decision activity and $I(a) \neq \varnothing \wedge O(a) \neq \varnothing$ indicates that there are inputs and outputs for the decision activity a.
- $I_{da} \subseteq I(a)$, $O_{da} \subseteq O(a)$, respectively present the inputs and outputs of the decision d^a.
- $L_{da} \subseteq L$, presents the decision logic of the decision d^a. A Decision Table (DT) is commonly used for presenting the decision logic in DMN. In this case, a commonly used reasoning construct in decision models, L_{da} is the DT of decision d^a demonstrating decision rules, and I_{da} and O_{da} contain the names of the input and output elements respectively.

To extend the DMN constructs with sub-decisions and contextual data, the following theorems are presented as the formal basis to utilize the decision modeling technique DMN to allow process variability by being aware of the context of a business process.

Theorem 1. $\left(d^{a'} \in D_{dm}\right) \wedge \left(\left(d^{a'} \leftrightarrow d^{a}\right) = False\right)$

Note that not only data is the input of a decision activity, but sub-decisions are another source of input, such that, if $d^{a'}$ is also a decision node of the DRD of d^a, and $d^{a'}$ is not the same decision with d^a, then $d^{a'}$ is a sub-decision of d^a.

Theorem 2. $IR \subseteq (D_{dm} \times D_{dm}) \cup (D_{dm} \times ID)$

Moreover, $IR \subseteq (D_{dm} \cup ID) \times D_{dm}$ is equal to $IR \subseteq (D_{dm} \times D_{dm}) \cup (D_{dm} \times ID)$. More specifically, $D_{dm} \times ID$ presents a decision node has a data input, and $D_{dm} \times D_{dm}$ presents a decision node has a sub-decision input.

Theorem 3. $DI_{da} \cup DecI_{da} = I_{da}$

The inputs I_{da} of the decision d^a consists of data inputs DI_{da} and decision inputs $DecI_{da}$ (i.e., the sub-decision $d^{a'}$ of the decision d^a).

Theorem 4. $(IR_{da} \neq \varnothing) \wedge (DI_{da} \neq \varnothing)$

Any decisions including sub-decisions need data inputs, which means these decisions are not leaf (end) nodes of a DRD.

Theorem 5. $(MI_{da} \cup C_{da}) = DI_{da}$

MI_{da} is provided manually or intentionally, other leaf inputs of decisions (i.e., data inputs) are collected from the context C_{da} including raw contextual data (e.g., IoT sensors, GIS) or contextual variables that are obtained by aggregating and processing various sensor data.

5 A Proposed DMN-Based Method for Context-Aware Business Process Modeling

The main objectives of the proposed DMN-based method is to provide a mechanism and methodology for correctly modeling business processes that fit their contexts and thus are able to properly execute across different situations by using decision models. Figure 2 outlines the methodology of the proposed DMN-based method, which consists of three phases including: (a) integrated modeling of the base process, (b) modeling the process variants, and (c) modeling the context of the business process. In

particular, context leads to process variability by affecting decisions of a business process, since contextual data is used to make decisions in gateways or calculate in decision activities. Hence, in a business process without decisions, context-awareness is normally not needed for the business process.

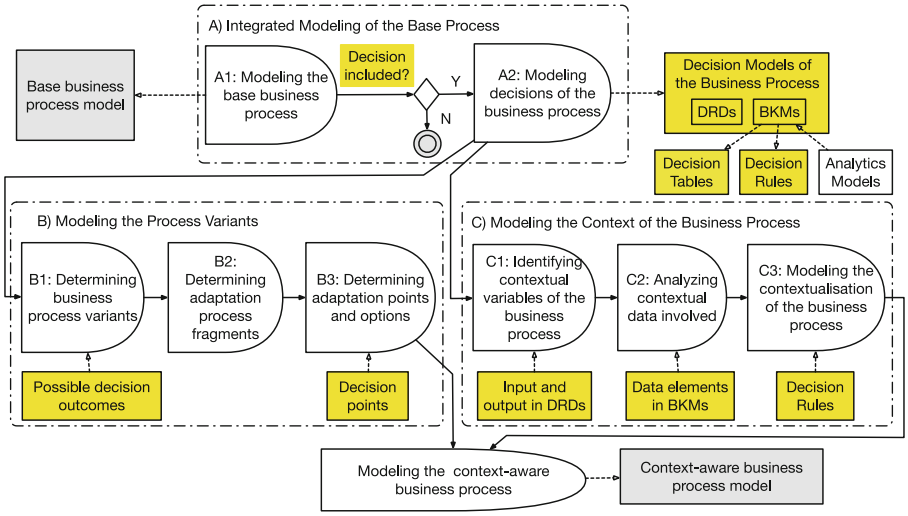


Fig. 2. The methodology of DMN-based method to model context-aware business processes.

5.1 Integrated Modeling of the Base Process

Firstly, the base process should be modeled in an integrated way, which means modeling decisions separately from the process flow and then obtaining a process-decision model for the initialization. In this way, decisions are not hidden in a business process as intricate control flows that can result in cascading gateways. The DMN technique is used to model the decision dimension of processes as decision models, including information requirements and the decision logic. After identifying and modeling decisions of a business process, the resulting model must be subsequently integrated with the process model. Consequently, an integrated process-decision model consists of the process workflow, DRDs presenting information requirements and the BKMs presenting the decision logic, which is the base to include context afterwards.

A1: Modeling the Base Business Process

Initially, the base business process is modeled in a traditional way. We propose a process of a customer buying a product as an example to depict how this DMN-based method works in applications. Figure 3 presents the base business process of this small example [12]. In this case, we model the business process based on BPMN (Business Process Model and Notation) in a procedural way, but CMMN (Case Management Model and Notation) can also be used to combine with the DMN technique to model

the decision-process integrated model in a declarative way, especially for flexible business processes.

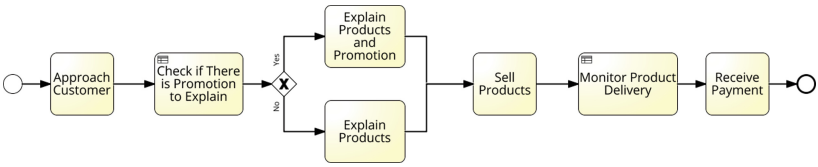


Fig. 3. The base business process of the small example.

Then we analyze this base business process to check if there are decisions involved. When a customer comes into a store, a salesperson needs to approach the customer and then check if there is any promotion to offer for increasing the customer's purchase intention. Then we identify "check if there is any promotion to explain" is a decision, and leads to a gateway for indicating the next step of the salesperson, i.e., explaining the product and promotion or explaining only the product. After selling products to the customer, products need to be monitored before the customer gets them delivered. Hence, the activity "monitor products delivery" is identified as another decision, since it needs input and has output constituting different calculation in various situation. Finally, the store gets the payment for these sold products.

A2: Modeling Decisions of the Base Business Process

After identifying decisions involved in the base business process, we need to model the decision dimension which consists of information requirements and the decision logic. Figure 4 depicts the DRDs of the base business process, which presents the information requirements level.

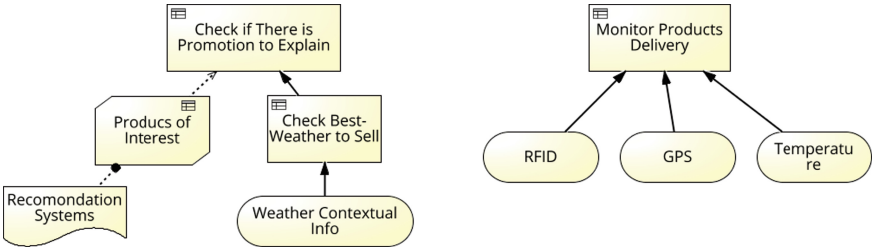
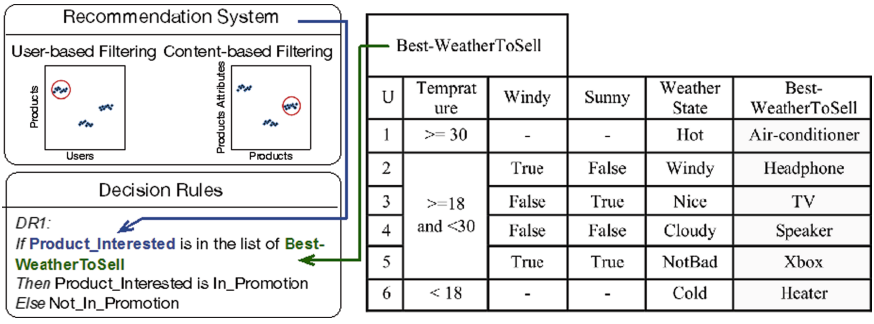


Fig. 4. The DRDs of the example.

The decision "monitor products delivery" needs "RFID", "GPS" and "temperature" as inputs to execute. More specifically, RFID can be used to invoke the identity information of products; GPS can be used to track the location of the delivery; and temperature can be needed to monitor the status of the delivery especially for fresh products such as milk or seafood. The other decision "check if there is promotion to explain" depends on products that the customer is interested in and bestsellers of

different weather states which needs certain contextual information of weather as inputs. Furthermore, the BKM of "products of interest" is needed to provide customer's preference, which depends on the recommendation system. Outcomes of the recommendation system provide inputs to determine the products of interest in terms of a customer. The capability of data analytics can then be utilized for decision making in this business process.

Then the decision logic needs to be modeled, which includes the BKM of "products of interest", the decision table of Best-WeatherToSell, and decision rules for checking promotions. Figure 5 depicts the decision logic representation involving data analytics. More specifically, the BKM of "products of interest" uses data analytics techniques, which could include user-based filtering and content-based filtering to provide recommendation for products that the given customer could be interested. The Best-WeatherToSell needs to follow several decision rules [12] that are presented in a decision table. Making the decision of checking promotion needs the decision rule to connect all elements involved in the decision logic. In addition, the decision logic of "monitor products delivery" could be a calculation to produce an array to output the delivery situation.



U	Temprature	Windy	Sunny	Weather State	Best-WeatherToSell
1	>= 30	-	-	Hot	Air-conditioner
2	>=18 and <30	True	False	Windy	Headphone
3		False	True	Nice	TV
4		False	False	Cloudy	Speaker
5		True	True	NotBad	Xbox
6	< 18	-	-	Cold	Heater

Fig. 5. The representation of the decision logic involving data analytics.

After these two steps, a process-decision model is obtained with a separate consideration of decisions and the business process.

5.2 Modeling the Process Variants

When the decision dimension of a business process is set, possible decision outcomes can be used to determine the process variability. Then possible process variants need to be modeled.

B1: Determining Business Process Variants
Different decisions outcomes lead to process variants. Especially strategic decisions, such as different requirements of production costs, quality control and safety monitoring, could trigger process changes. In this example, two process variants can be anticipated according to the outcomes of decision "check promotion", that are

"promotions to explain" or "no promotion to explain" if we take the context of promotion into consideration.

B2: Determining Adaptation Process Fragments
Then some process fragments need to be modeled to optimize or complete the base business process for responding to different situations towards process flexibility, personalized services or knowledge-intensive tasks. In this case, the activity of checking promotion and the subsequent activity of explain products and the promotion is modeled as a process fragment.

B3: Determining Adaptation Points and Options
Decisions can lead to partial process splits as a decision point, or result in different calculations of a decision activity. Moreover, these process splits result in process variants of one process goal. Hence, we need analyze possible process splits of the business process to determine how to configure the base business process and process fragments due to different decision outcomes. The decision points are the key indicators of adaptation points. Moreover, the adaptation options could be "insert before", "insert after", "around", "delete", etc.

5.3 Modeling the Context of the Business Process

After modeling the integrated decision-process model and process variants, the context of the business process need to be modeled as the stimuli for process variability. The information requirements of decisions are the key source to identify the context of the business process, since these data affects the decision making in this process and leads to process variability. The contextual variables, i.e., direct data inputs, need to be identified in the first place. If these variables can be collected directly from databases, sensors, IoT devices or applications, they can be considered as contextual data. Otherwise, we need to further analyze relevant contextual data that is essential to be processed to obtain certain contextual variables. The semantic rules are then needed to be presented for context reasoning, which must be consistent with decision rules to guarantee the correctness of context interpretation. These identified contextual data and semantic rules need to be organized in an extendible way. Hence, context models may be needed especially in which the business process embedded is complicated.

B1: Identifying Contextual Variables of the Business Process
The contextual variables can be identified according to data inputs in DRDs of a business process. These contextual variables are required as parameters for executing gateways to choose a process branch or calculating in decision activities.

According to the inputs of the DRDs, we can identify relevant contextual variables of the base business process, which are "weather contextual info", "weather state", "products of interest", "best-weather to sell", "RFID", "GPS" and "temperature" in this example.

B2: Analyzing Contextual Data Involved
After identifying contextual variables, we need to examine if these variables can be directly collected. However, some contextual variables can only be obtained by context fusion or context reasoning, so we need to further identify contextual data of lower

semantic level needed. Thus, the decision logic is the key source to identify contextual data involved, since these rules are the logic to get the intermediate variables to make decisions in the business process.

In this example, "weather contextual info" and data required in the BKM of "products of interest" is still not clear. Through analyzing the decision table of Best-WeatherToSell, we know that contextual weather information including "temperature", "windy or not" and "sunny or not" is needed for the contextualization of the business process, i.e., components of the context of the business process. The contextual data needs also to be analyzed if the analytical model of the BKM of "products of interest" is provided.

B3: Modeling the Contextualization of the Business Process
After determining the context of a business process, we need to organize contextual data and their relations in a context model, especially when a business process is embedded in a complicated context. Since semantic hierarchies exist in the context, a reference technique is also needed for modeling context. Different techniques have been proposed until now to model context [20]. Although all techniques have advantages and disadvantages, the ontology technique is one of the best choices to model context, which also allows the reasoning technique embedded. Note that the context modeling technique needs to be compatible with the process-decision modeling technique in order to ensure the usability of the context model. Since the context of this example is simple, we don't provide details for the context model in this paper.

After these three steps, the context of the business process is identified and organized using the decision models.

5.4 Modeling the Context-Aware Business Process

In this small example, the process variants are simple as a split of two exclusive activities "explain products and promotion" and "explain products". However, the design of process variants can be complicated in real world.

In this case, context affects the business process in two points of decision activities. One in the decision "check if there is promotion to explain", which leads to a gateway for flow variants in the business process. The other one is the decision "monitor products delivery", which leads to different performance variants in the business process. Through applying the DMN-based method, we finally obtained the context-aware business process, which allows process variability. Figure 6 depicts the final context-aware business process model of this example.

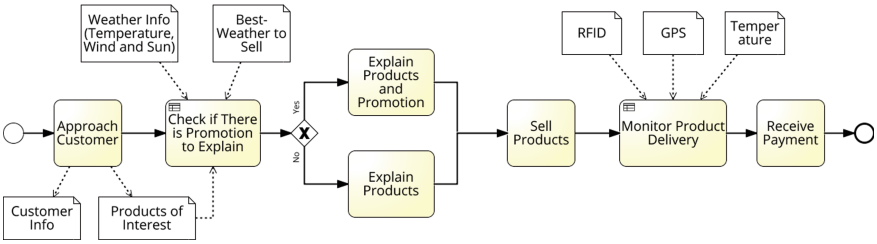


Fig. 6. The context-aware business process model of the example.

6 Discussion

Context is taken into consideration to model a complete and optimized business process at design time. Business process designers use decision models to integrate contextual data and anticipate possible situations for modeling a flexible or personalized business process.

Different types of context-dependent decisions could influence the context-aware business process from different perspectives, such as process flexibility, personalized services and knowledge-intensive tasks. As decision activities are more sensitive to context compared to operational activities and administrative activities in a business process, it is of importance to separately consider decisions from business processes, rather than considering decisions as a hidden and intrinsic flow in a traditional way of business process modeling. The DMN-based method proposed in this paper takes the separate consideration of decisions and processes which provides advantages of allowing process variability depending on dynamic context. It provides the methodology for the whole procedure of the context-aware business process modeling.

Context influences business processes and leads to process variability in both the flow and the performance levels. However, it is challenging to identify relevant contextual data of a given business process, especially in this data explosion world (ubiquitous and pervasive computing). This DMN-based method also provides a methodological way to guide the contextualization of a given business process, which can be used in any application domain. This also presents a straightforward path for researchers if they want to use decisions and rules to model context-awareness. Moreover, the capability of analytics can be integrated in the context-aware business processes and directly contributes to decision making based on the proposed DMN-based method.

7 Conclusion and Future Work

This work provides a DMN-based method for the separate consideration of decisions and processes, which allows to model context into decisions for achieving process variability.

Traditionally, decisions have been modeled as the hidden and intrinsic part of a business process, also in the context-aware modeling field. Such an approach impairs the maintainability, scalability, and flexibility of both processes and decisions, as well as the analytics capability of a business process. Only if a decision is improved as a result of analytics, we can argue that the analytics has value. Moreover, decisions and rules play key roles in context-aware business process modeling, including determining the need of context-awareness, the anticipation for the context-awareness and the contextualisation of a business process.

In order to use the decision modeling technique DMN to model context-aware business processes, a formal presentation of DMN is presented and extended in particular for context-awareness, as the theoretical preliminary of the proposed DMN-based method. The main contribution of this paper is proposing a DMN-based method to model context-aware business processes systematically with less reliance on experts.

Using this method, the role of analytics in improving parts of decision making can also be integrated in context-aware business process modeling. The more specific role for analytics increases the potential for using big data and analytics, which leads to decision-making improvement and the business process with that decision-making involved.

In future endeavours we will investigate a real-world case for applying the proposed method in more detail. Especially in the IoT paradigm, achieving context-awareness in business process modeling for process variability is significant. Moreover, context modeling techniques such as the ontology technique are interesting to involve in the future solution.

Acknowledgments. This research is supported by the Natural Science Foundation of China under Grant 71502010.

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