BPMN for Disaster Response Processes – A methodical extension

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Abstract: The application of business process management (BPM) methods to disaster response management (DRM) is a frequently discussed issue. Although it is seen as very challenging the potential benefits of BPM-methods to increase effectivity and efficiency in planning and monitoring the several activities of disaster management and their related resources are promising. The use of a standard modelling language like Business Process Model and Notation (BPMN) is recommended because of its prevalence and maturity of available tools. However, the standard set of elements in BPMN is not comprehensible enough to take account of some special requirements of DRM like importance of place-related information or multiple different resources. The research in this paper presents a methodological extension of BPMN based on an ontology of critical DRM-interrelations used to enhance the BPMN meta-model.

Keywords: BPMN-Extension, disaster response process, process modelling, spatial information

1 Process Modelling in Disaster Response

Disasters caused by natural phenomenon or human fault are a threat to assets as well as human life. In order to minimize potential damages and facilitate an effective and efficient disaster response management (DRM) contingency plans are designed in advance. In case of disasters these plans are extended and concretized for creating suitable disaster response processes to counteract the current situation [Ch08]. However, these processes are mostly on an abstraction level which necessitates much interpretation and additional information that is manually taken into account by responsible disaster managers. Since DRM is usually very complex due to the high amount of different involved resources and organizations as well as many parallel activities, the management of resulting disaster response processes (DRP) can be very challenging. Keeping all necessary information in mind is nearly impossible for disaster managers [Ch08, FC10].

To overcome this problem the application of business process management (BPM) methods to the DRM domain for planning and structuring processes is discussed [FW09, RW07, SHB13]. An extensive literature reviews shows that most of these process-aware approaches are designed for a special purpose and provide a very technical view on their functions [HBS15]. Although these approaches address important DRM issues they have mostly not established in practice. A common problem is that practitioners are not familiar with the provided view on processes and the related models and tools. A standardized

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comprehensible modeling language is missing in the domain.

On the other hand, the BPM domain offers a wide variety of process modelling languages. The similarities of business processes and DRP (e.g. event-driven, comprise activities, resources and actors required to execute the activities, etc.) give point to adapt an established BPM-Method to this new domain [Ho14]. BPMN is one of the business process modeling languages with the highest prevalence and internationally used. It comes with a manageable set of standardized elements and allows a comprehensible visualization of processes. On the other hand BPMN also facilitates process automation, which is a necessary requirement for approaches for IT-supported processing of processes e.g. in workflows. In this regard BPMN is a compromise between usability and support of technical features, which other modeling methods like the semi-structured Event Driven Process Chain are lacking.

With these explanations in mind the following research question is discussed in this paper: Can BPMN be extended to allow the consideration of domain specific requirements of disaster response processes?

In this approach we present a methodological extension of the well-structured BPMN standard following Stroppi et al. [SVC11b]. This extension can easily be implemented in conventional process management tools for a quick and comprehensible application in disaster management practice. The paper is part of the comprehensive research project "DRP-ADAPT" aiming at the adaption and improvement of BPM-methods to support the management and processing of the highly DRP with a so called disaster response workflow management system (DRWfMS). A special focus of the project is the flexible, automated composition of underspecified DRP using the spatial information of used resources. DRP-ADAPT is structured following the Design Science Research Process by Peffers et al. [Pe06]. While former publications addressed the phases of (1) problem identification (e.g. [HBS15, SHB13]) and (2) objectives of a solution (e.g. [Ho14]) as well as (3) design and development of first parts of the solution (e.g. [Be15]) the paper at hand aims at the design and development of the process modelling component of the solution artifact. The next chapter provides the basis for the extension by deriving and discussing six requirements of DRP modelling from the literature. A comparison to the BPMN-standard in chapter three shows the necessity of an extension, which is done in chapter four following the method of Stroppi et al. [SCV11b]. The results are discussed with a view on related work. The paper closes with a short conclusion and an outlook on further research.

2 Requirements for DRP-Modelling

The set of requirements presented in this section was chosen in regard to the goals of the higher research effort of the DRP-ADAPT project. Therefore the requirements focus on characteristics for spatial coordination of resources in disaster situations [SHB13]. However, as the discussion shows they are important for DRM in general. Since literature provides many sources for further requirements, we suggest the enhancement of the approach in future publications to build a comprehensive DRP modeling language.

One major problem in regard to DRP is the effective and efficient allocation of required resources. Research publications addressing this issue discuss different problems for different kinds of resources. At this, most approaches differ between human resources like response teams, fire fighters or volunteer helpers and non-human resources like fire engines, medical supplies or equipment [CZ07, RT10]. These different kinds of resources need to be taken into consideration in the modelling of DRP. Whereas the human resource is specified by its role in DRP, the non-human resource is primarily specified by its features and use cases. Resources can depend on each other. The collaboration of different engaged organizations needs to be addressed by the process model in order to ensure effective and efficient resource allocation [DMD07]. **R1: A DRP model must allow the distinction between human and non-human resources as well as depiction of interdependencies between those.**

Both resource types have different features that may influence the applicability of a process. Non-human resources describe a wide set of different materials, gadgets and tools. The usage of some resources is limited by their consumption through finite capacity. In general a non-human resource is either consumable or non-consumable [CL10, SHB13]. A non-consumable resource, for example a fire truck, can be allocated by multiple activities consecutively, without necessity to restock its capacity, whereas a consumable resource, like water to extinguish a fire, is limited for multi-consecutive use. The resulting main differences for these two characteristics are the need to plan reloading activities and considering the limitation of consumable resources. The modelling of this feature helps to identify required support activities. **R2: A DRP model must allow distinction between consumable and non-consumable resources.**

Another feature of non-human resources whose impact on the applicability of DRP is discussed in the literature is the multi usability [SHB13]. Multi usability means the possibility of a resource to be used by different activities at the same time (e.g. a fire engine is used to extinguish fire as well as evacuate people with help of the onboard ladder). The two characteristics of this feature are multi usability and single usability. The decision about simultaneous execution of activities by the same resource is ceded to the process modeler who should have knowledge about capabilities of relevant resources. **R3: A DRP model can comprise multi usable and single usable resources.**

		Task-Relevant Knowledge		
		Task-Specific	**General Domain**	**Little**
Knowledge of Disaster Response	**Extensive**	Super-expert	Functional semi-expert	Functional inexpert
	Some	Expert	Semi-expert	Functional inexpert
	Little	Specialist	Semi-specialist	Inexpert

Tab. 1: Types of actors in disaster response [Ju07]

Human resources in DRP are usually specified by the role they take on in their allocated activities. The roles that a human resource can fill depend essentially on the knowledge of the resource. According to Jul there are two dimensions of knowledge which determine the role of human actors in a DRP [Ju07]. The dimensions and their resulting user types are illustrated in Table 1.The task-relevant knowledge estimates the the proficiency of a resource in a certain activity. For example a person is an expert in using a water pump in general. The second dimension of knowledge is based on the experience with disaster response scenarios. The water pump expert may be comfortable in using the machine but was never involved in a flood and has little knowledge of disaster response. In total he is classified as a specialist. The two dimensions of knowledge are separated because of their different effects in sorting human resources to activities. The DRM domain provides far more specific resource types, e.g. combined resources for special situations [Po07], which are not addressed in this paper due to the limited scope but could be addressed in future research. **R4: A DRP model must consider different user types for human resources.**

Independent from characteristic features of resources, their current status in time-critical processes is crucial. To provide a good overview about the status of resources, six different states are discussed. According to Großkopf the important states are: *enabled* (1), *not allocated* (2), *allocated* (3), *started* (4), *suspended* (5), *completed* (6) [Gr07].A resource is *enabled* when it is part of the DR system. In case of a human resource this would be e.g. the registration as a volunteer by an aid organization. A *not allocated* resource differs from an *enabled* resource in this way, as it is currently useable. This could be a human resource whose user type is already determined and which is ready to help in a defined activity. For a non-human resource we additionally assume that *not allocated* means defined multi usability and consumption type. E.g. a defined consumable, non-human resource would be in state *not allocated* when its quantity is loaded. An *allocated* resource is dedicated to a certain activity. When the resource is already in-place for its activity and is executing its task, we assume it as *started*. A resource is *suspended*, when it is currently not able to fulfill its purpose. An empty consumable, non-human resource is an example for that. A resource with status *completed* has finished its task. Depending on the use case it would be possible to provide more detailed status information but these six general statuses are applicable to every possible resource in the process. **R5: A DRP Model must consider different states of resources.**

The final requirement of this work refers to spatial information, which is discussed as particularly important in DRP [SHB13]. Spatial characteristics of activities and resources can highly affect the feasibility of a process and need to be considered in planning and execution of DRP. Two minimal features are discussed to describe the spatial status: mobility and location. The most common way to describe a location is the usage of latitude and longitude. This information is applicable for resources as well as activities and can be translated to a possibly existing address. In terms of mobility there are two different characteristics: stationary and mobile. A stationary resource is limited for the use in activities in its area, whereas a mobile resource is able to move or being transported to an activity where it is needed. A stationary activity must be executed at its destined location, e.g. the building of a dam. A mobile activity can be conducted at various locations, e.g.

the filling of sandbags. **R6: A DRP model must comprise spatial information in regard to activities and resources.**

All DRP-relevant aspects discussed in previous explanations have been merged and illustrated in the ontology presented in figure 1. We provide this overview as basis for further proceeding in this paper. The resource is an entity which has a relation to itself representing the dependencies between resources (**R1**). The appended features are resource status and the spatial information mobility type, longitude and latitude (**R5**, **R6**). The class "Human" inherits from the entity resource as it is the representation of the human resource (**R1**). The human specific feature is the user type (**R4**). "Non-human" inherits from "Resource", as well (**R1**). The non-human resource specific features are multi usability and consumption type (**R2**, **R3**). Finally the human resource entity is related to the activity for representing the executing subjects (*does*) whereas the link between activity and the non- human resource represents all further resources that are used for execution (*uses*). The spatial information attributes are attached to the activity, to complete the domain scenario (**R6**).

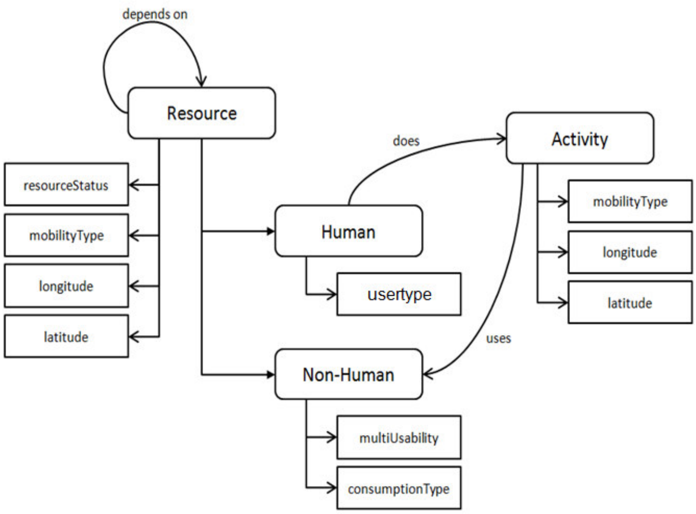

Fig. 1: Disaster-Response problem domain ontology

The overview reveals that all of the six requirements are related to resources of a DRP since, all requirements, with the exception of one (**R6**), are exclusively aiming at a better definition of resource entities. Therefore further explanations in this work also focus on issues in regard to resources.

The derived set of requirements is not claimed to be complete but outlines a clear area of interest for modelling DRP: resources and spatial information. Furthermore existing works like the generic DRP model of Betke support the findings in this work and also highlight the importance of these DRM specific challenges [BE15]. However, a starting point for derivation of further requirements can be found in [HBS15] which gives an exhaustive overview about process aware approaches in DRM. The paper at hand focuses on the requirements defined in this chapter but is open for future enhancement.

3 Current Situation in BPMN Standard

In this chapter the BPMN standard is investigated regarding the ability to address the required information for DRP. Therefore the two main entities from the ontology in section two, resource and activity, are examined regarding standard attributes which can be used to describe required features.

The activity inherits from `flownode`, as shown in figure 2. This is an abstract class which is the foundation of all entities in BPMN which can be lined in process sequences. `Flownode` inherits from `baseElement` which is the abstract superclass for all viewable elements in BPMN. So all inherited properties from activity are abstract and cannot support the problem specific requirements for spatial information [OM13].

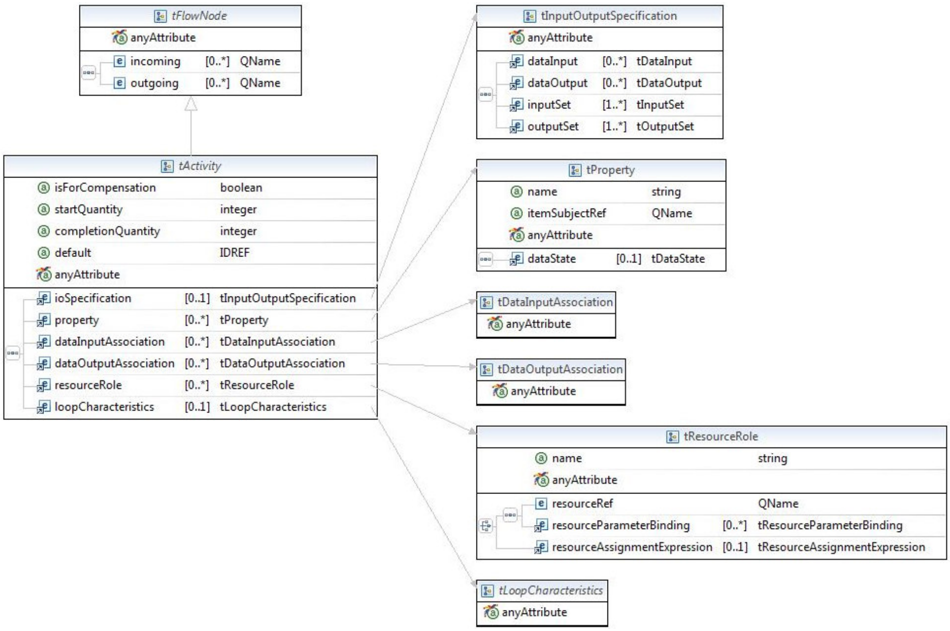

Fig. 2: Meta-model of activity in BPMN [OM13]

The specific activity properties describe the trigger of the activity regarding a compensation event *isForCompensation* or regarding a counter to start *startQuantity* and to stop *completionQuantity*.Related entities describe the handling with data associations concerning input *dataInputAssociation* and output *dataOutputAssociation*. Furthermore loops can be implemented with the attribute *loopCharacteristics* and resources can be allocated resourceRole.

In summary with the relation to `resourceRole` it is possible to represent dependencies between activities and resources. There is no opportunity to express activity specific attributes because the related property class is underspecified as well. This means, that it is not possible to include spatial information of an activity. With possible relations to activities the `resourceRole` needs to be evaluated next.

Resources are abstract and underspecified in BPMN. The only possibility to model them is the `resourceRole` entity shown in figure 3 which is intended to represent a human resource [BE14].

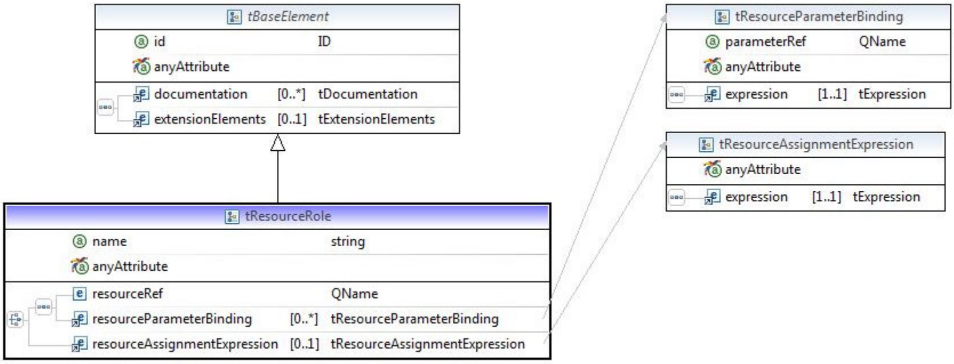

Fig. 3: Meta-model of resourceRole [OM13]

The `resourceRole` inherits directly from `baseElement`, so it is not possible to represent sequences like in activities and the resource does not have inherited properties. With the related entity `resourceParameterBinding` an abstract resource parameter can be expressed. Additionally it is possible to get a relation to an activity `resourceAssignmentExpression` shown in the previous evaluation ([OM13]).

The `resourceRole` does not have any specific properties to address attribute requirements from section two. But the meta-model of BPMN does already contain a possible relation to activity and there are references which indicate an opportunity to represent specific resource attributes. In conclusion the BPMN standard does not fulfil Building the BPMN Extension

Addressing the lack of DRP-specific elements in BPMN shown in the previous chapters, the method from Stroppi et al. [SCV11b] is applied to provide a suitable extension. The method uses a MDA-based approach, which means BPMN is extended through UML-formulated meta-models. The transformation in the meta-meta-model level makes the extension useable for automation and BPMN tools. This MDA-based model extension is state-of-the-art [FV04; La07; Se07].

The method to get a correct syntax for a BPMN extension consists of four steps.

1. Definition of the Conceptual Domain Model of the Extension (CDME) in UML.
2. Definition of the BPMN + Extension (BPMN+X) models in form of a BPMN Extension.
3. Transformation of the BPMN+X model into a XML Schema Extension Definition Model.
4. Transformation of the XML Schema Extension Definition Model into a XML Schema Extension Definition Document [SCV11b].

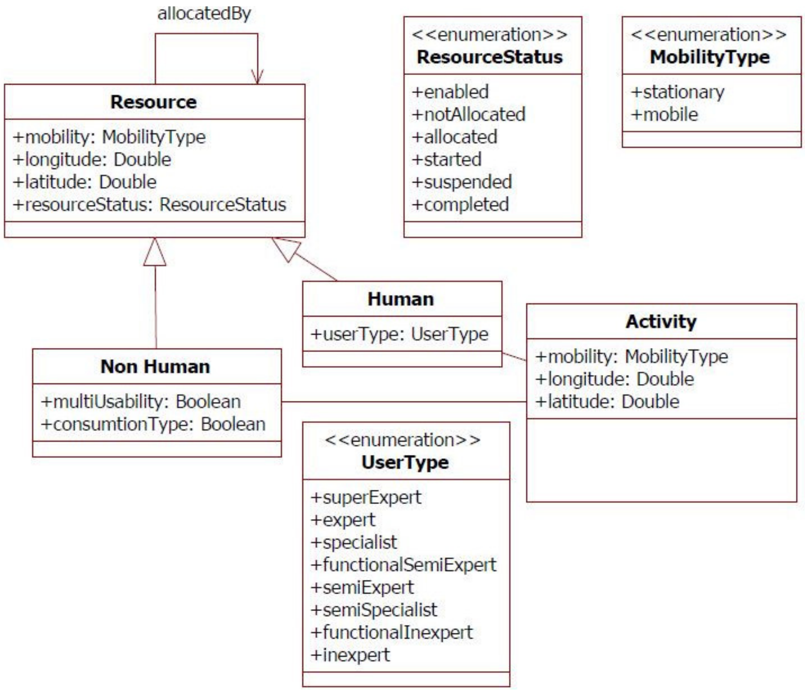

Fig. 4: DRP CDME

Note that this work only performs the first two steps of Stroppi et al. procedure. Step three which transforms the BPMN+X model into an XML schema extension definition model and step four which transforms this into an XML schema extension definition document (XSD) is for automation of process models. This work focuses on the model expression of BPMN for DRP and on the usability in process build time.

The UML class diagram shown in figure 4 is the transferred representation of the requirements ontology from section two. This diagram is the foundation for the usage of the transformation steps. It represents the first step in the defined approach named

Conceptual Domain Model of the Extension (CDME).

The activity is related to the specified subversion of the resource class: human and non-human (**R1**). The properties of activity are *mobility*, *longitude* and *latitude* (**R6**). The data type of the property *mobility* is an enumeration mobilityType which consists of *stationary* and *mobile*. The data type of *longitude* and *latitude* is double which ensure the required accuracy of the location.

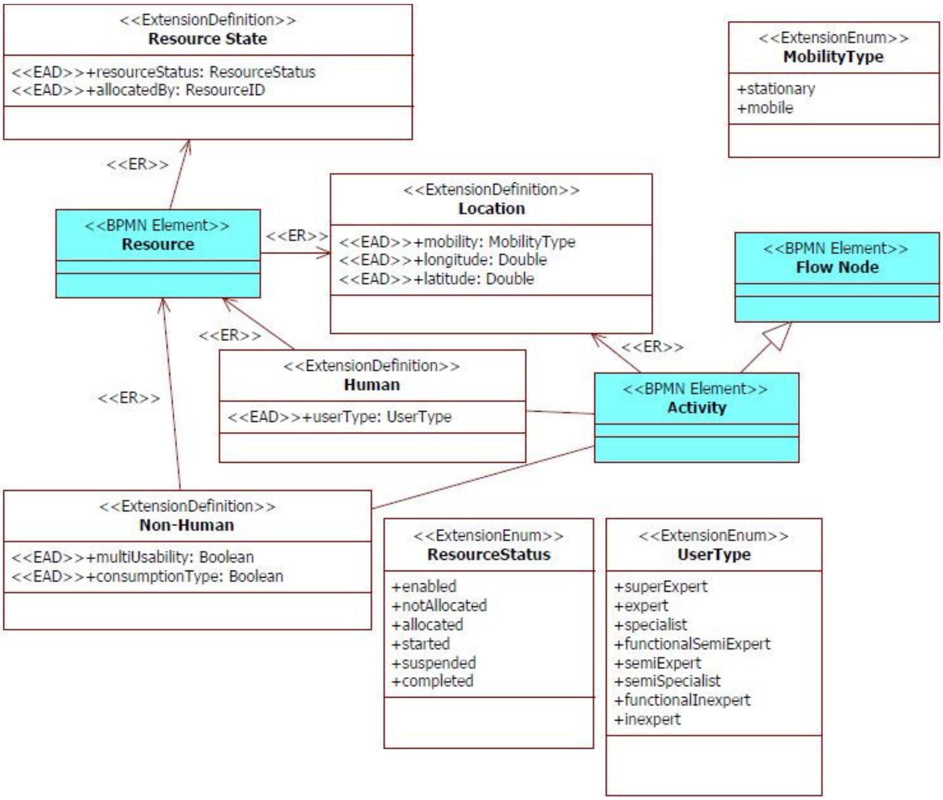

Fig. 5: BPMN+X model for DRP

The resource is inherited by human and non-human. Resources can depend on other resources which is represented by the relation to itself *allocatedBy* (**R1**). The spatial properties are part of the resource, so they can be used by human and non-human resources (**R6**). The *resourceStatus* has the data type enumeration resourceStatus with the characteristics *enabled*, *notAllocated*, *allocated*, *started*, *suspended* and *completed* (**R5**).

The class human is specified by the property *userType*. The data type of *userType* is an enumeration userType in form of *superExpert*, *expert*, *specialist*, *functionalSemiExpert*,

semiExpert, *semiSpecialist*, *functionalInexpert* or *inexpert* which addresses the requirements for the knowledge of users from previous sections (**R4**).

The `non-human` class has the specific properties *multiUsability* and *consumptionType* which are both of data type Boolean (**R2**, **R3**). This data type enables an intuitive use-case for the declaration of these attributes for non-human resources. The value true for *multiUsability* means that a resource is multi useable and false means that it is single useable. For *consumptionType* the value true means that the resource is consumable and false means that it is not consumable.

After application of the transformation of the proposed proceeding the final BPMN+X model looks as shown in figure 5. The coloured classes are part of the BPMN standard and provide the interfaces for the extended classes.

To use this BPMN+X model in the build-time of process modelling it is necessary to introduce suitable icons. The extension enumerations `extensionEnum` are meta information for the model, so it is not required to define icons for these classes. That is why we need icons for the extension definitions `resourceState`, `non-human`, `human` and `location`. Additionally recommended text annotations for the new icons are introduced. These annotations make it possible to visualize the specified property characteristics extended in the extension enumerations.

Fig. 6: Definition of extension icons

Figure 6 shows a suggestion for icons to visualize the new elements from left to right:

1. Resource State (ExtensionDefinition Resource State)
2. Location (ExtensionDefinition Location)
3. Non-Human (ExtensionDefinition Non-Human)
4. Human (ExtensionDefinition Human)

The `resource state` is displayed with an example text annotation *allocated*. This annotation can have one of the characteristics defined in the extension enumeration `resourceStatus` (**R5**). he advantage of this description is the straightforward identification of whether or not a resource related to an activity is able to fulfil its task.. The annotation of the *allocatedBy* attribute is considered as non-comfortable and, hence, not implemented. The resource state is an extension definition which is related to the BPMN element resource. Because of the resource being an abstract BPMN element, the resource state can only be appended to a non-human or human icon (**R1**).

Location is defined by tripartite annotation. The first element of this annotation describes the *mobility* (*mobile* or *stationary*) and the second and third elements represent the *longitude* and *latitude* (**R6**). By defining the decimal length of longitude and latitude it is possible to specify the accuracy of the location. The location extension definition is referenced by two BPMN elements, so the only way to model that dimension is an appendix to an activity or a sub version of the resource which is human or non-human.

The non-human icon is displayed with two text annotations. The first characteristic defines the multi usability and the second the consumption type. Because of the data type being Boolean the following semantic is recommended (**R2**, **R3**).

- `If (multiUsability == true) then` „*multi use*" `else` „*single use*"
- `If (consumptionType == true) then` „*consumable*" `else` „*non consumable*".

The non-human extension definition is related to the BPMN element activity, so it can be appended to any activity element. The human icon shows an example text annotation *specialist*. This annotation represents the characteristics defined in the extension enumeration user type (**R4**). Similar to the non-human class, the human extension definition is related to the BPMN element activity and may therefore be appended to any activity element as well.

The four new icons for BPMN and their specific annotations allow the consideration of all six requirements derived in chapter two.

4 BPMN-Extensions in Related Work

In this chapter we give a short overview on the related work to emphasize the novelty of the results. A comprehensive literature review on process-oriented approaches in DRM already revealed the lack of a process modeling language suitable for DRP [HBS15]. Therefore, we take a further look at approaches for extending BPMN in other domains. Due to the prevalence of BPMN and the well documented standard there is a wide range of approaches proposing extensions for various fields of application. As highlighted in section two the modelling requirements used in this paper mostly refer to the resource element and its process-relevant features in regard to spatial aspects. In conclusion the following comparison of related work focuses on respective approaches. The determined works are shortly discussed regarding the extension language for use in BPMN, the examined problem domain and the usability of the results for DRP.

In 2007 Großkopf published a work, in which BPMN was extended for a better description of resources. The paper is related to process automation and it uses a rule-based model to extend information [Gr07]. In comparison to the present approach the lack of integration into the BPMN extension meta-model is standing out. So it is difficult to use it in standard tools. The extended resource attributes are partially taken into the requirements of DRP (R5) but must be implemented differently.

In 2009 Awad et al. presented a BPMN extension for human resources. The extension is associated with the meta-model but there is no usage of BPMN extension classes. The extended information is modeled using OCL constraints [Aw09]. Because of the general focus with no specific problem domain there is no accordance regarding requirements from the DRP model approach.

2011 Stroppi et al. extended BPMN for a better expressiveness regarding resources. The extension was made on meta-model level, which was introduced in BPMN at this time and used the BPMN extension classes [SCV11a]. With special focus on business processes-relevant resources the approach has no specific relation to the requirements of this work.

In 2014 Braun et al. published a work based on the methodology from Stroppi et al. [BE14, SCV11b], to extend BPMN for modeling production procedures in industrial application. The extension has a user-friendly definition of icons for extended entities. In the evaluation part of this approach, the method of Stroppi et al. was proven to be correct which supports the choice of the method for the paper at hand. Although some requirements regarding the resources are similar to the DRP requirements the approach covers a different domain and cannot take all requirements like e.g. involvement of spatial information **(R6)** into consideration.

The investigation shows, that the method of Stroppi et al. [SCV11b] is commonly used to extend BPMN. Although some issues regarding resources in processes are addressed, the requirements of DRP where not yet taken into account.

5 Conclusion and Outlook

This work aimed at the extension of BPMN to cover DRP-specific requirements. Six requirements could be identified from the literature and were used to build an ontology capturing all affected process elements in a single model. Based on that the approach of Stroppi et al. was used to extend the meta-model BPMN and define a representation of new BPMN entities. A look at existing research papers showed that the paper at hand stays in line with other approaches using the method of Stroppi et al [SCV11b] to extend BPMN, but exclusively addresses the requirements of the DRM domain.

The results of this paper show, that BPMN can be extended to cover domain specific characteristics of DRP. The new set of elements can already be used by practitioners in any tool which supports BPMN-extensions. Although six important requirements in regard to DRP-modelling are addressed a far more comprehensive extension is possible and requirements could be discussed more detailed. Future research could enhance the current approach by considering issues like resource interdependencies. to Furthermore, a promising advancement of the current paper would be the application of the last two transformations by Stroppi et al. As a result process aware information systems could be enabled to allow the automation of DRP models and developed to serve as disaster response workflow management systems. In regard to the DRP-ADAPT project this paper described the design and development of the modeling component. Following the Design Science Research Process [Pe06], further publications will address the phases of demonstration and evaluation. A tool will be created to conduct experiments with DRM practitioners on the one hand and experienced BPMN users on the other hand to give evidence of the practical benefits and applicability of this BPMN extension.

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