Automated Analysis and Adaptation of Disaster Response Processes with Place-Related Restrictions

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ABSTRACT

For recent years, disaster response management is considered as a promising field for applying methods and tools from business process management. Especially the development of adaptive workflow management systems (WfMS) brought a process-oriented management of highly dynamic disaster response processes (DRP) within tangible reach. However, time criticality, unpredictability or complex and changing disaster reality make it impossible to analyze and adapt ongoing DRP within reasonable time manually. Hence, to foster the application of disaster response WfMS in practice, it becomes mandatory to develop methods supporting an (semi-)automated analyses and adaption of ongoing DRP. Addressing this research gap, we present a novel method called DRP-ADAPT which analyzes given DRP models with respect to place-related conflicts and resolves inoperable response activities (semi-)automatically by process adaptation.

Keywords

Disaster Response Management, Workflow Management Systems, Process Analysis, Process Adaptation, Business Process Management

INTRODUCTION

Right after a man-made or natural disaster has occurred, effective and efficient disaster response processes (DRP) have to be initiated in order to restore the safety of systems, humans and/or assets. Therefore, contingency plans are usually prepared in advance and executed during disaster response (Rao, Eisenberg and Schmitt, 2007; Chen, Sharman, Rao and Upadhyaya, 2008; Turoff, White, Plotnick and Hiltz, 2008). Since DRP are similar to business processes (e.g., activity centred, event-driven, goal-oriented, reliant on resources and actors, etc. (Hofmann, 2014)), business process management (BPM) provides a promising approach to improve disaster response management (DRM) (e.g. Fahland and Woith, 2009; Betke and Hofmann, 2014; Rüppel and Wagenknecht, 2007; Sell and Braun, 2009; Marjanovic and Hallikainen, 2013). So called disaster response workflow management systems (DRWfMS) have been discussed to facilitate a systematic coordination of ongoing DRP by providing methods and functionality for an (semi-)automated process execution, enhanced information management, coordination, communication, delegation and increased process transparency (e.g. Sell and Braun, 2009; Hofmann, Sackmann and Betke, 2013; Jansen, Lijnse and Plasmeier, 2010; Ziebermayr, Huber, Kollarits and Ortner, 2011).
However, DRM is faced with one particular challenge (beside many others) that is unknown in BPM and

pretending the use of DRWfMS in practice: the unknown place of process execution due to the inherently unpredictable place of disaster occurrence. Whereas business processes can be comprehensively pre-specified to fit a well-known execution environment by design (e.g., with respect to machine and/or resource locations), this is almost impossible for DRP since the resource situation on-site as well as the necessary supporting response activities only reveal when the disaster strikes. Depending on the actual place of disaster and resulting restrictions, the operability of DRP could be compromised or become unfeasible at all (e.g. destroyed access roads stop fire fighting vehicles). Hence, pre-specified DRP have to be concretized at runtime, continuously analysed with respect to place-related restrictions and, at best, adapted "on the fly" to suit the actual disaster reality (Rao et al., 2007; Sackmann, Hofmann and Betke, 2013).

From a technical point of view such ad hoc adaptations can be achieved in modern DRWfMS providing functionalities for insertion, deletion or shifting of activities in workflow instances (e.g. Lanz, Kreher, Reichert and Dadam, 2010). However, to the best of our knowledge, such DRWfMS have not yet been realized in practice. One main reason might be the lack of methods assisting DRWfMS users in process adaptation itself. Faced with a continuously changing and intransparent disaster reality, a plethora of interdependencies and restrictions between response activities and resources occur. In addition, since numerous DRP usually must be analysed and adapted simultaneously, process adaptation becomes impossible to be managed manually "with the naked eye" (Rao et al., 2007; Hofmann, 2014, TRIDEC, 2013). Rather, it is mandatory to provide methods supporting a (semi-)automatic process analysis of place-related restrictions, of changing context data, as well as an automated reasoning and calculation of necessary process adaptations (Hofmann, Betke and Sackmann, 2013b).

Addressing this research gap, we developed a novel method called DRP-ADAPT which is capable to (1) analyze given DRP-models with respect to place-related restrictions, (2) identify inoperable response activities and (3) determine appropriate process adaptations in order to recover the operability of the underlying DRP-model. By realizing these tasks (semi-)automatically, DRP-ADAPT has potential to foster the applicability of DRWfMS in practice and to prevent faulty, ineffective or inefficient process adaptations caused by human errors or capability constraints. In order to present the research artefact in a proper and understandable way (Gregor and Hevner, 2013), the contribution is organized as follows: the next chapter provides detailed insights into the state of the art of current BPM-related research approaches in DRM. Afterwards the applied research method is briefly explained. Subsequently, section four presents DRP-ADAPT as research artefact in a detailed manner. The contribution concludes with a first evaluation and discussion of limitations and remaining research desiderata.

BPM IN DRM

The idea of applying methods and tools from BPM in DRM can be traced back until the last millennium (for a comprehensive literature review see (Hofmann, Betke and Sackmann, 2015)). In this regard, at least two general research fields have emerged:

(1) Using modelling languages from BPM for preparing DRP. Research aims especially at simplification of modelling languages and development of DRM-related modelling elements (Ziebermayr et al., 2011; Peinel, Rose and Wollert, 2012) as well as surveying and analyzing reference process models in DRM (Franke, Widera, Charoy, Hellingrath and Ulmer, 2011; Lindemann, Prödel and Koch, 2010). Therewith, research outcomes lay a foundation for a process-oriented DRM in general.
(2) Applying process aware information systems (PAIS), i.e., DRWfMS for advanced management of DRP and automation.

However, DRP-models usually remain complex and confusing due to, e.g., numerous modelled alternatives, exceptions, involved roles, actors or resources. Moreover, pre-specified DRP-models do usually not match actual disaster reality and have to be adapted during runtime (Chen et al., 2008; Le Clair and Moore, 2009; Swenson, 2010). Thus, in case of emergency, expressiveness and utility of process models is often doubted (Franke, Charoy and Ulmer, 2010; Peinel, Rose and Wollert, 2012). This issue is addressed by DRWfMS intended to hide complexity and to provide methods and functionality for (semi-)automated process configuration, coordination, flexible process execution and process evaluation. However, for applying WfMS in DRM, they need to address special domain requirements as discussed in (Hofmann et al. 2013). The following selected DRWfMS approaches reflect a state of the art in this research field (Hofmann et al., 2015):

- The Collaboration Management Infrastructure (Baker et al., 1999) offers traditional WfMS functionality in order to support coordination of response tasks and actors. It is based on pre-specified process templates which have to be manually selected and instantiated in case of disaster occurrence. To reduce complexity, responders see only activities they are responsible for. Process flexibility is supported by pre-specified activity placeholders remaining unspecified at design time and becoming replaced by at runtime. However, process monitoring, analysis and selection of necessary process adaptations are shifted to experts and must be carried out manually.

- WORKPAD (Catarci et al., 2006) allows late specification of response activities that can be assigned during the disaster to appropriate mobile devices of on-site responders (e.g. taking pictures from a certain place). It automatically monitors and maintains on-site peer-to-peer mobile ad hoc network (MANET). WORKPAD determines if on-site responders move out of MANET range and manages other responders to close the gap by moving in a coordinated way. However, WORKPAD does not provide functionality for monitoring or sustaining the operability of the DRP itself: process monitoring, analysis and selection of necessary adaptations remain a manual tasks for experts.
- The "framework for coordination of activities in dynamic scenarios" presented in (Franke, Charoy and El Khoury, 2013) is based on clearly specified response activities and their temporal dependencies (e.g. "evacuate people" can be executed simultaneously with "firefighting"). If activity state changes, several algorithms present identified violations of restrictions to the disaster manager. The framework also relies on manual intervene and analysis in regard to appropriate process adaptations and does not consider place-related restrictions.
- A similar approach focussed on resource interdependencies is presented in (Wang, Tepfenhart, Rosca and Tsai, 2007). Their DRWfMS allows even unexperienced users to model, execute and analyze DRP. A novel method for analyzing and simulating resource availability within a given DRP model is proposed. However, place-related restrictions are neglected and process adaptation still remains a manual task for experts.
- At present, only a few research addresses the automated analysis and adaptation of DRP: for instance, (Ziebermayr et al., 2011) ask for systems which (semi-)automatically select appropriate DRP and response activities from a "disaster response process pool". (Rüppel and Wagenknecht, 2007) claim for methods that support process analysis and adaption, e.g., by suggesting possible alternatives. However, there are neither elaborated nor evaluated research outcomes in either of these contributions.
- The only approach actually developing a method for an (semi-)automated analysis and adaptation of DRP is presented in (Sell and Springer, 2009). They propose the complementation of existing DRWfMS by an adaptation layer responsible for calculating necessary process adaptations under consideration of temporal interdependencies. Adaptations must be confirmed by disaster managers and, thus, can be implemented and assigned to on-site responders in a semi-automatic manner. However, interpretation of context data and selection of appropriate response activities is shifted to an abstract “context service” that is out of the research scope.

Summarizing the state of the art, no comprehensive DRWfMS-approach is available that provides adequate methods for process analysis and adaptation considering the relevance of "place" and place-related restrictions in a comprehensive manner. Indeed, most DRWfMS basically support process adaptation at runtime but do not provide assistance for analysing ongoing processes in order to determine necessary and appropriate process adaptations. Thus, only few research approaches address the automated analysis of DRP with respect to temporal and resource-related restrictions. Their focus lays on detecting and visualizing violations, the suggestion of possible alternatives or even a (semi-)automated process adaptation is hitherto out of scope. Only Sell and Springer (2009) present a technical solution–unfortunately the definition of DRM-related restrictions, violations and adaptations are not solved. However, to our view, this is one of the main challenges that must be overcome in order to make DRWfMS applicable to DRM in future.

RESEARCH METHOD

The contribution at hand follows the design science paradigm which focuses on the creation of novel and useful artefacts, i.e., constructs, methods, models, instantiations and/or design theory for information systems. These artefacts must contribute to the knowledge base within a certain research branch, either by improvement, expatiation or invention (Gregor and Hevner, 2013; Hevner, March, Park and Ram, 2004). DRP-ADAPT is such a novel artefact, a method contributing to the knowledge base in both DRM and BPM. In regard to DRM, existing DRWfMS approaches are improved by a method capable to analyse and adapt DRP-models in a (semi-) automated manner and, thus, to reduce need for manual interventions which is seen as crucial prerequisite for making DRWfMS applicable. Furthermore, DRP-ADAPT considers systematically place-related restrictions in process models for the first time. This might also facilitate the extension of known solutions from BPM to new problems (expatiation), i.e., making BPM applicable to new application areas characterized by uncertain places of process execution (e.g., "on-the-fly" logistic).

As research methodology, we follow the research processes suggested by (Peffers, Tuunanen and Rothenberger, 2007) and (Nunamaker, Chen and Purdin, 1991). Whereas the former provides an approach for structuring design science research projects in general, the latter lays greater emphasis on the actual artefact development (Table 1). Moreover, as suggested by (Hevner et al., 2004), an iterative search process was implemented that was accompanied by several intermediate research contributions (step 6 in (Peffers et al., 2007)) in order to receive feedback from the scientific community. The contribution at hand summarizes the previous research results, links them to the phases of the research process (third column of Table 1) and provides novel insights into the artefact evaluation.

Peffers	**Nunamaker**	**Related papers**
(1) problem identification and motivation	(1) construct a conceptual framework	• Hofmann et al., 2013b • Hofmann et al., 2015
(2) define objectives of a solution		
(3) design and develop the artefact	(2) develop a system architecture	• Hofmann et al., 2013
	(3) analyze the design of the system	• Sackmann et al., 2013
(4) demonstration	(4) build the (prototype) system	• Sackmann et al., 2013b • Betke and Hofmann, 2014 • Hofmann, 2014
(5) evaluation	(5) observe & evaluate the system	• Hofmann et al., contribution at hand
(6) communication	-	(see above)

Table 1. Research methodologies of (Peffers et al., 2007) and (Nunamaker et al., 1991) and related papers

Since research problem and research objective (step 1 & 2 (Peffers et al., 2007) resp. step 1 (Nunamaker et al., 1991)) have already been outlined within the introduction, the following chapter explains the developed artefact (step 3) in detail.

ARTEFACT DESCRIPTION

This chapter consists of four subsections describing the central research outcomes of DRP-ADAPT. According to step 2 of (Nunamaker et al., 1991), we first developed a system-architecture (Hofmann et al. 2013), i.e. an extended DRWfMS architecture allowing the application of an automated analysis and adaptation of ongoing DRP. The analysis and design of our actual research artefact DRP-ADAPT (step 3) extends the knowledge base by formalizing "place" in process models. Moreover, a framework for place-related conflicts that must be considered when analyzing and adapting DRP is presented. DRP-ADAPT consists of two novel methods: one for process analysis and one for process adaptation. A first version of the analysis method called PRIMA is capable to detect place-related conflicts within simple DRP-models but cannot yet consider different branch-operators (Sackmann, Hofmann, Betke, 2013b). Thus, within a following research cycle, PRIMA was extended to PRIMA II (Betke and Hofmann, 2013) being capable to detect place-related conflicts within complex process structures. Based on the results of PRIMA II, a novel method for resolving place-related conflicts and for adapting DRP was developed (Hofmann, 2014).

The extended DRWfMS architecture

From a technical side, current DRWfMS are based on adaptive WfMS which provide functionalities for runtime adaptation of workflow instances. This adaption is mostly realized as instance-migration which means to suspend the running workflow instance, adapt its underlying workflow scheme and, based on this, continuing the suspended workflow (e.g. Reichert, 2010; Eberle, Leymann and Unger, 2010). However, analysis of running DRP instances as well as the adaption of their underlying workflow scheme are still manual tasks and automation is only rarely addressed (e.g. Kittel, Sackmann, Betke and Hofmann, 2013; Sell, 2010). Hence, current DRWfMS approaches must be complemented by an additional analysis and adaptation module performing the required analysis and adaptation of suspended DRP-instances and underlying workflow schemes (Hofmann et al., 2013).

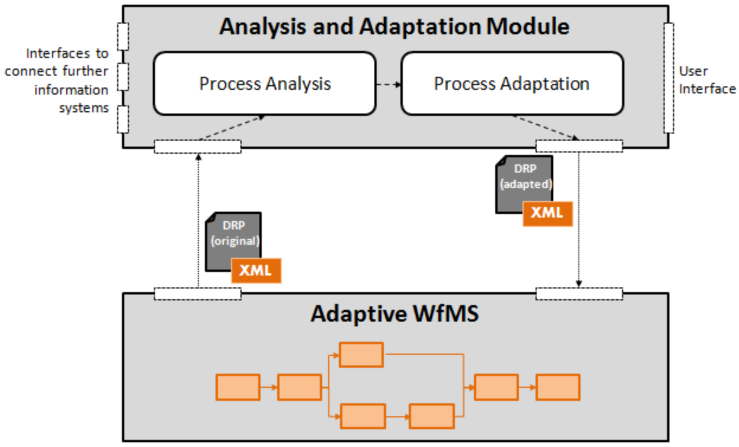


Fig. 1. DRWfMS architecture (cf. Hofmann et al., 2013)

For this purpose, a formal description of a DRP instance must be submitted to the analysis and adaptation module. There it can be analysed, adapted, and transferred back to the execution engine of the DRWfMS. After successful retransmission, the original DRP model is replaced by the adapted one and, therewith, provides the new workflow scheme to be continued. The extended DRWfMS architecture and the basic procedure are illustrated in figure 1.

A crucial prerequisite for this procedure is the feasibility to extract the formal description of a suspended workflow instance via appropriate interfaces from the execution engine (e.g. as XML-document). However, this does not indicate a problem, since modern WfMS usually provide a variety of interfaces for integration of third-party applications (Workflow Management Coalition, 1995) as well as import and export functions for workflow schemes. To ensure applicability of DRP-ADAPT to various DRWfMS approaches, we decided to use a language-independent and formal graph-based representation of the DRP. Since most workflow modelling languages are based on graphs (e.g. Eberle et al., 2010; Reichert and Weber, 2012) the internal representation of workflow schemes can be easily converted by specific wrappers into a standardized XML-document and vice versa.

Formalization of “place” in DRP-models

Since in business processes the place of process execution as well as storage/usage locations of resources are usually defined and fixed at design time, traditional BPM considers "place" at best indirectly. Contrary to DRM, where actual places of process execution do not reveal until the disaster strikes. Thus, they can only be considered during run-time of DRP. As a necessary precondition for any automated analysis or adaptation, it is crucial to provide appropriate modelling elements that allow the description of place-related attributes in process models. A first approach is presented in (Sackmann et al., 2013), where activities and resources are defined to be either stationary or mobile. In addition, they are enhanced by location characteristics, i.e. longitude and latitude or just an abstract identifier of the location (Table 2).

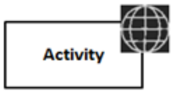
Type	Stationary resource	Mobile resource	Stationary activity	Mobile activity
Description	can be used only at their site	can be used independently from site	can only be executed at a certain place	can be executed at different places
Example	water hydrant	emergency generator	extinguish fire	build emergency shelter
Modelling element	 Longitude/Latitude	 Longitude/Latitude	 Longitude/Latitude	 Longitude/Latitude

Table 2. Model elements for place-related information in DRP (cf. Sackmann et al., 2013)

A framework for place-related conflicts

The introduced modelling elements are used to describe a framework for different place-related conflicts in DRP-models. Thus, mobile and stationary activities and resources are related to each other based on possible mutual dependencies, i.e., activity-to-activity, resource-to-resource and activity-to-resource dependencies. This leads to 12 dependency-categories which characterise different conflict situations whenever "places" of related elements differ. For instance, a stationary activity "firefighting" can only be executed if the required resources (e.g., firefighting vehicles) are located at the execution place of the firefighting activity. In case of a deviation, the DRP might no longer be executable and, thus, needs adaption (e.g. by transport) in order to recover its operability. Due to the variety of possible conflict situations and associated solutions, it is proposed to develop case-specific analysis and adaptation methods (Sackmann et al., 2013).

Within the framework of our research project we particularly focused as first step on the identification of place-related availability-conflicts between stationary activities and mobile resources. Such conflicts are well-known in DRM, since response activities usually must be executed at a fixed place, i.e., the affected disaster area, and the required resources need to be taken on-site.

The Analysis Method PRIMA II

In order to determine the operability of a given DRP-model, we developed an algorithm which analyzes each activity whether it requires a resource and whether the resource is located at the activity's execution place. To give an example, we designed a (for didactical reasons clearly over-simplified) DRP with only two activities: "load emergency vehicle" followed by "build shelter" (Figure 2).

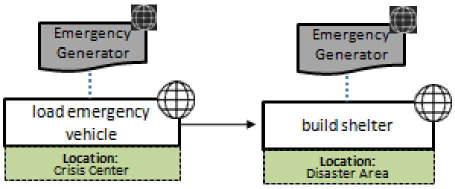


Fig. 2. Example DRP

Both activities have to be executed at different places, i.e. the former at the Crisis Center and the latter at the Disaster Area. Since both activities will be executed in sequence (one after another), the emergency generator is required at varying places during execution. However, the DRP model does not specify, how to get the mobile resource from one place to another. As long as locations of Crisis Center and Disaster Area differ, a place-related resource conflict occurs during runtime of the DRP.

In order to detect such conflicts, the PRIMA algorithm (Sackmann et al., 2013b) identifies resource paths along the formal graph representation of any given DRP by backward-oriented graph search. For each resource requesting activity is analysed, whether there is a direct sequential predecessor that also requests the considered resource. Therewith, the last-known place of resource usage can be determined so that comparison of execution places is feasible. In case of a mismatch, inoperability of the subsequent activity is detected. To take also different branch-operators, i.e., XOR and AND, into consideration, an improved algorithm called PRIMA II was developed and presented in (Betke and Hofmann, 2013) which is capable to distinguish and interpret different branch structures in order to detect associated conflicts.

Process Adaptation by Insertion of Transport Activities

The result of PRIMA II is a list of all identified place-related conflicts within a given DRP model. In order to resolve them, we propose to adapt the DRP by insertion of additional transport activities bringing resources to the "right" place of activity execution. In relation to the example mentioned above, the place-related conflict can be solved by inserting an intermediate transport activity from crisis centre to the affected disaster area (Figure 3). In order to avoid process hampering, e.g. in case of other non-resource related activities, we decided to insert the transport activity on a parallel branch.

As briefly discussed before, resource requesting activities are not necessarily arranged sequentially but also in parallel. Hence, we analysed the elementary five workflow patterns presented in (van der Aalst, ter Hofstede, Kiepuszewski and Barros, 2003), i.e. sequence, parallel split, synchronization, exclusive choice, simple merge. For all of them possible place-related conflict situations and associated adaptation strategies are identified (Hofmann, 2014). Those strategies have been formalized in rules that can be used to facilitate an (semi-) automated adaptation of DRP in order to recover their operability. Therefore the "valid" DRP-adaptation is suggested to responsible (human) decision maker (resp. disaster manager) who has to evaluate the proposed solution with respect to the general context of DRM and to select/confirm the adaptation for instantiation.

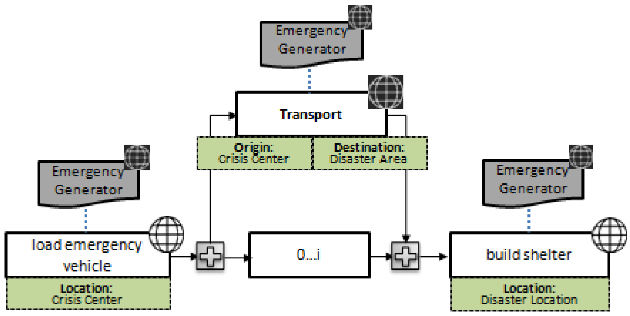


Fig. 3. Adapted example DRP

DEMONSTRATION AND EVALUATION

As proof of concept, PRIMA II and the adaptation rules have been prototypical implemented in order to demonstrate their processing. According to our DRWfMS architecture, AristaFlow BPM Suite[1] is used as adaptive WfMS providing the required functionality for runtime adaptation of DRP as well as the conformance check of adaptations. AristaFlow BPM Suite offers a user interface for modelling graph-based DRP and has been extended by an interface for importing and exporting formal descriptions of DRP as XML-file. We developed also an additional analysis- and adaptation module, connected to AristaFlow BPM Suite. Each time, a DRP is instantiated or changed (e.g. because of manual intervention or external events detected by an event handler), the running DRP is suspended. Then, a XML-description of the current DRP and its state of execution is generated and sent to our analysis and adaptation module. Therein, the model is analysed and adapted according to DRP-ADAPT and send back to the WfMS. After reading the new XML-file, AristaFlow BPM Suite checks the syntax as well as other formal correctness criteria and, finally, continues the suspended DRP based on the adapted model.

This procedure has been tested several times and for various DRP models with different levels of complexity, giving promising results. Unfortunately, the evaluation of DRP-ADAPT cannot be conducted within case studies because of several reasons: DRWfMS are not yet applied in practice but only discussed as promising approach by researchers. In fact, practitioners are just at the beginning in terms of the discovery and utilization of methods and tools from BPM and can hardly imagine the application of such systems to DRM. Hence, up to now, it is nearly impossible to find test panels willing to take an active part in such a case study. Moreover, the maturity level of current DRWfMS approaches is not yet sufficient to be applied to a domain wherein assets or life are in danger. In particular, an extensive analysis of requirements for using DRWfMS in DRM (Hofmann et al., 2015) reveals several crucial requirements which cannot be met yet, not even by applying DRP-ADAPT.

Faced with such immense challenges, we decided to evaluate the correct processing of DRP-ADAPT by testing

[1] http://www.aristaflow.com/

and experimenting (Hevner et al., 2004). Therefore, we have to demonstrate that

(1) PRIMA II exhaustively identifies place-related conflicts within a DRP-model (**completeness of analysis**) and
(2) that adaptation rules reliably resolve them without producing any new conflicts (**reliability of adaptation**).

Since PRIMA II identifies place-related conflicts by a specially developed and performance oriented backward graph search algorithm, it is necessary to prove that no conflicts are overlooked (1st objective of evaluation). Hence, we decided to analyse given DRP-models a second time, using a proven but very time-consuming method which would provide the counterevidence in case that PRIMA II is incomplete. Therefore, we make use of so called execution sequences known from business process mining. Within an execution sequence all activities are ordered sequentially and there are no more parallel (AND) or alternative (XOR) branches. Usually, they result from the actual order of activity execution at runtime of a process (e.g. in (Sadiq, 2007)). However, it is also feasible to determine possible execution sequences in advance by a tree-search crawling. Depending on the complexity of the underlying process model (e.g., in regard to the number of activities, nesting depth and combination of AND-/ and XOR-structures) this obviously requires a high computational power and is very time-consuming but well suited for evaluation since place-related conflicts cannot be overlooked. This is due to the fact that execution sequences only consist of unambiguous and clear predecessor/successor pairs which can be analysed in regard to place-related conflicts.

Based on this exhaustive list of all possible execution sequences, DRP are analysed again in regard to place-related conflicts in order to determine a comparable set of possible conflict situations. If PRIMA II produces the same results as detected within the execution sequences and this can be demonstrated for many DRP, its completeness and correctness can be substantially assumed. To give an example for the processing of the evaluation method, we designed an abstract DRP (Figure 4) containing seven activities. a_2, a_6 and a_7 require the same resource and are connected by different branch operators.

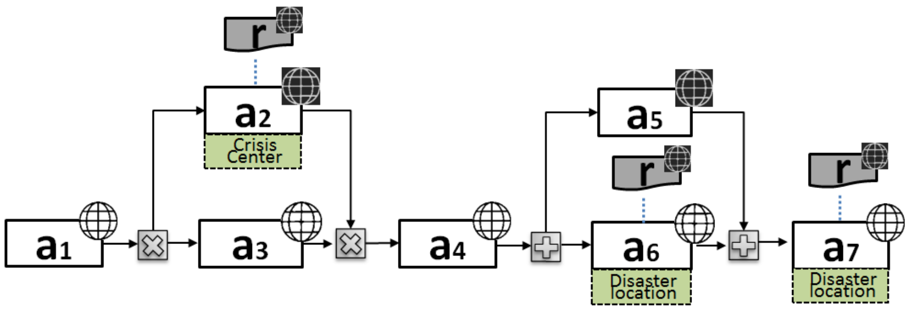


Fig. 4. Abstract DRP-model

Assuming that even concurrent activities located at parallel branches are executed in a sequential order, this results in an exhaustive list of four possible execution sequences: S1 = $(a_1-a_2-a_4-a_5-a_6-a_7)$; S2= $(a_1-a_2-a_4-a_6-a_5-a_7)$; S3= $(a_1-a_3-a_4-a_5-a_6-a_7)$ and S4 = $(a_1-a_3-a_4-a_6-a_5-a_7)$. As a next step, for each resource requesting activity, all possible resource-related predecessors are searched (Table 3).

	Resource-related predecessors in:			
Examined activity	S1	S2	S3	S4
a_2	*none*	*none*	*none*	*none*
a_6	a_2	a_2	*none*	*none*
a_7	a_6	a_6	a_6	a_6

Table 3. Resource-related predecessor activities in execution sequences

Removing duplicates from the list of predecessors reveals four resource-related predecessor/successor pairs which have to be analysed in regard to place-related conflicts: (*none*-a_2), (a_2-a_6), (*none*-a_6) and (a_6-a_7). According to PRIMA II algorithm, such conflicts arise whenever predecessor's and successor's execution places differ. Hence, the places of execution of these pairs are taken into consideration and are compared to each other.

An activity without a resource-related predecessor means that the activity uses the resource for the first time and, thus, its place of execution is compared with the original storage location of the resource. In our example DRP, the resource is assumed to be stored at the crisis centre. Thus, a conflict appears in all execution sequences wherein activity a_2 is predecessor of a_6 and/or activity a_6 is the first activity which requires the resource (Table 4).

predecessor/successor pair	Validation results	Interpretation
(*none*-a_2)	Crisis Center = Crisis Center	Operable
(a_2-a_6)	Crisis Center != Disaster Area	Inoperable
(*none*-a_6)	Crisis Center != Disaster Area	Inoperable
(a_6-a_7)	Disaster Area = Disaster Area	Operable

Table 4. Result-list of the evaluation method

In order to evaluate the completeness of the results of PRIMA II we applied the outlined method for identifying and analysing execution sequences several times to various DRP models with different levels of complexity. Although irrefutable evidence is not achievable, the comparison of the results provides a verification of PRIMA II's correct processing.
In order to prove the reliability of the adaptation rules (2nd objective of evaluation), we simply re-examined the adapted DRP with aid of PRIMA II. Since the process adaptation should resolve all identified place-related conflicts in an appropriate manner and may not produce any new conflicts, the re-examination may no longer raise any conflicts. This was also checked and shown for a variety of DRP models.

CONCLUSION AND DISCUSSION

In this contribution, a novel method called DRP-ADAPT and its concrete implementation was presented which enables a (semi-)automatically analysis of given DRP models with respect to place-related conflicts and resolves them by automated process adaptation. Thus, current DRWfMS are improved and extended by taking the relevance of "place" as well as the time critical, unpredictable and changing nature of disasters into consideration. We also presented and classified PRIMA II as novel analysis method which is capable to identify place-related conflicts in processes and provides a basis for a novel adaptation method inserting additional transport activities into DRP models. Furthermore, an extended DRWfMS architecture is presented that offers an additional analysis and adaptation module wherein DRP-ADAPT as well as other methods for an (semi-) automated process analysis and adaptation can be realized.

Therewith, DRP-ADAPT contributes to both, research in BPM as well as in DRM. We extended the knowledge base in BPM by formalizing "place" in process models and developed a framework for identifying and resolving place-related conflicts. This facilitates the applicability of methods and tools from BPM to new application areas which are characterized by uncertain places of process execution.

Regarding the contribution to the research field of DRM, DRP-adapt is still based on several assumptions and limitations which lacking in practical relevance. For instance, PRIMA II expects resources to be non-divisible and non-consumable. In future research resource bottlenecks, scarcity and resource consumption must be taken into consideration when reconstructing resource paths. Moreover, at its current state of development, DRP-ADAPT is only capable to resolve place-related conflicts between stationary activities and mobile resources and disregards conflicts that may appear from any other place-related conflicts between interdependent mobile/stationary resources and activities. Although it is not expected that the approach changes in general, fundamental changes might be implemented in order to overcome these limitations. Rather, the development of DRP-ADAPT is only one step of many others that are necessary to create a comprehensive DRWfMS that can actually be tested within focus groups and, later on, applied in practice.

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