# A Novel Architecture for Disaster Response Workflow Management Systems

**Marlen Hofmann**
Chair of Information Science and Information Management
Martin Luther University, Halle, Germany
marlen.hofmann@wiwi.uni-halle.de

**Stefan Sackmann**
Chair of Information Science and Information Management
Martin Luther University, Halle, Germany
stefan.sackmann@wiwi.uni-halle.de

**Hans Betke**
Chair of Information Science and Information Management
Martin Luther University, Halle, Germany
hans.betke@wiwi.uni-halle.de

## ABSTRACT

Due to the shared focus of disaster response management (DRM) and business process management on activities as well as the obvious similarity of disaster response processes (DRP) and business processes, the application of workflow management systems (WfMS) has been discussed as a promising approach to manage DRP. However, the application of WfMS in DRM has not yet been realized in practice. One reason for this is the lack of methods and tools in WfMS for taking interdependencies between activities, time, resource, and place into consideration. This considerably restricts the variety of DRP. Therefore, a novel architecture for a disaster response workflow management system is discussed. A special focus lies on the management and analysis of interdependencies that is seen as very promising to improve future DRM.

### Keywords

Disaster response management (DRM); workflow management systems (WfMS); interdependency management

## MANAGING DISASTER RESPONSE PROCESSES WITH WORKFLOW MANAGEMENT SYSTEMS

In non-trivial disaster response situations, the echelon of tactical disaster response management (DRM) is concerned with coordinating various decentralized and parallel-operated disaster response processes (DRP) (Chen, Sharman, Rao and Upadhyaya, 2008). In this regard, the effective adaptation of ongoing DRP to new situations is one of the main challenges: changing activities, resources and their states, place, and time lead to complex as well as unpredictable restrictions. These changing restrictions require continuous adaptation so that DRP remain operable and end in an overall effective disaster response. Several methods and tools for the necessary information management, communication, coordination, and provision of process transparency are proposed and discussed in various fields of research (see, e.g., discussion in (Hofmann, Sackmann and Betke, 2013)). One promising field is Business Process Management and, in particular, the use of so-called adaptive WfMS. These systems provide increasing flexibility as well as various methods and tools for a systematic management of alternative and parallel workflow instances (Dadam, Reichert and Rinderle, 2007). Moreover, workflow-based analytical approaches are considered to provide a plethora of opportunities regarding an improved management of DRP (Hofmann et al., 2013).

This contribution focuses on facilitating the applicability of WfMS in the field of DRM. Thus, it is aimed at providing a sound basis for developing novel disaster response workflow management systems (DRWfMS). The following section starts with a short discussion of a general approach for DRM, highlighting dependencies and restrictions on activities related to time, place, and resources. Based on this, requirements for a holistic and integrated DRWfMS are derived from literature in section three. Section four discusses the state of the art and shows that existing approaches do not cover them adequately. Subsequently, we present a novel architecture for DRWfMS and explain it with the help of an exemplary case study. The paper closes with a short conclusion and open research questions.

## CHALLENGES IN MANAGEMENT OF DISASTER RESPONSE: PROCESS DESIGN AND EXECUTION

DRM refers to the management of DRP to counteract a disaster in the immediate aftermath of its occurrence aiming at recapturing control and protecting life and assets (Chen et al., 2008; Fahland and Woith, 2009; National Research Council, 2006). Thus, DRM is a main part of a more general process for disaster management which is concerned with mitigation, readiness in the case of an emergency, management of disaster response itself, and activities to recover from disaster.

DRM is usually divided into the phases of design and execution. Within the former, emergency plans are concretized according to the disaster reality and available context information so that operable DRP can ultimately be initialized. Within the execution phase, single process activities have to be assigned to the staff and executed on-site. In this phase, on-going DRP are subject to continuous adaptation due to changing disaster reality, information situation, or goals.

This adaptation is mainly challenged by taking a multiplicity of resource, temporal and spatial dependencies into consideration (Franke, Charoy and Ulmer, 2010; Sell, Winkler, Springer and Schill, 2009) which might considerably restrict both the possibilities for counteracting a disaster and the feasibility of single response activities. Moreover, these dependencies cannot be taken into consideration in an isolated way since they mutually influence each other, e.g. if the location of a disaster event determines the deployable resources which, again, determine the available activities that can be carried out. Such dependencies are interdependent and should therefore be analyzed and assessed simultaneously for an effective DRM. Furthermore, DRM is faced with time pressure, uncertainty and an imperfect information situation (Chen et al., 2008; National Research Council, 2006) so that appropriate process design and adaptation easily becomes a complex and challenging task which strongly relies on a sophisticated information management as well as on transparency of on-going DRP. Thus, the development of adequate methods and tools for providing both is a challenging endeavor and a highly relevant research field.

## FUNCTIONAL REQUIREMENTS FOR DRWFMS AND RELATED WORK

WfMS have been discussed as a promising approach to manage DRP in various contributions, e.g. (Jansen, Lijnse and Plasmeijer, 2010; Sell and Braun, 2009). However, to the best of our knowledge, the application of WfMS in DRM has not yet been realized in practice. One reason for this might be the neglect of several inherent and indispensable requirements in DRM and, hence, the absence of a holistic DRWfMS which satisfies all of them. Analyzing previous research (Beroggi and Wallace, 1995; Chen et al., 2008; Georgakopoulos, 1999; Hofmann et al., 2013, Sell, 2010), the following functional requirements on an integrated DRWfMS can be derived:

**Design Phase:** since design and concretization of DRP is accomplished under time pressure, it can be assumed that responsible information managers are not able to spend much time on modeling DRP in a machine readable and executable manner. Thus, designing process models has to be at least semi-automated. This leads to the first three requirements in regard to the design phase of DRP:

- R1. A (semi-) automated selection of appropriate response activities considering available context data.
- R2. A (semi-) automated analysis of interdependencies and restrictions resulting from time, place, and resource situation in order to determine appropriate DRP.
- R3. An automated determination and proposal of feasible DRP models.

**Execution Phase:** Although DRWfMS provide potentials for automating processes, it is clear that the execution of DRP itself cannot be expected to become automated in general, especially not on the operational level (e.g. firefighting must still be carried out by firefighters). However, available methods and tools for managing workflows open up new opportunities for enhancing process transparency by providing a separated but interconnected view on asynchronous DRP instances. Moreover, there are possibilities for partial automation (e.g. requesting of resources), identification of time advantages, or determination of conflicts by analyzing and monitoring on-going process instances. Therefore, an appropriate DRWfMS should provide at least the following functions:

- R4. Provision of an adaptive WfMS which allows real-time adaptation of underlying DRP models.
- R5. (Semi-)automated instantiation of proposed DRP models and automated updating of DRP states.
- R6. Provision of information access on contextual data (e.g. Geo Information Systems, ERP Systems, etc.) in order to ensure that data can be considered for an automated design and adaptation of DRP.

R7. Provision of a graphical user interface for visualization of emerging conflicts, decision-making, and manual intervention (e.g. with regard to the entry of further information, adding, replacing, shifting, or deletion of activities and resources or manual state updating).

Of course, these requirements are not exclusive. There are further requirements which have to be considered (e.g. with regard to usability, resource management, task delegation, communication, etc.). Since these functionalities can already be realized in "classical" WfMS, they are not further discussed in this contribution.

## CURRENT APPROACHES FOR DRWFMS

Approaches addressing an automated selection and determination of appropriate response activities (R1 and R3) are manifold. A first type relies on so-called process repositories, i.e. alternative process models specified in advance and selected in the case of an emergency. The selection is made at run-time and based on available context data (see, e.g., Fahland and Woith, 2009; Lin and Jun, 2008). A second type of modeling approaches is based on automation of process modeling: (Heinrich, Klier and Zimmermann, 2011) propose an automated modeling by predefined process fragments, ontology, and several new algorithms. However, these approaches have not yet been integrated into WfMS and, therefore, they do not provide the required run-time functionality. Furthermore, the consideration and analysis of interdependencies (R2) is at best mentioned parenthetically.

Approaches analyzing interdependencies between activities, resources, and time (R2) are usually model-based and do not deal with an automated consideration in WfMS either. Nevertheless, they offer various methods addressing at least sub problems which are associated with DRWfMS, e.g. a formal representation and modeling of temporal and resource restrictions as prerequisite for automated processing (see, e.g., Hofmann et al., 2013). However, to the best of our knowledge, there are no approaches addressing spatial interdependencies in processes (R2). Interdependency between place and activities, resources, or time is not explicitly formalized. Modern DRM strongly relies on spatial information, e.g. provided by geo information systems (GIS) in order to gain access to geo data from the place of the disaster. For instance, deNIS II plus and WebEOC are well known examples of DRM systems offering comprehensive functions to improve disaster response planning in general. Although spatial information is of particular importance for efficient and effective DRP, current approaches do not provide functions or methodical support for design, execution, and management of DRP taking these interdependencies and the resulting restrictions adequately into consideration.

Regarding R4, R5, and R7, technically oriented approaches are focused on the development of adaptive WfMS. For instance, iTask, ADEPT, or AristaFlow® BPM Suite provide functions for (semi-) automated insertion, deletion, change, or shifting of activities in workflow instances as well as manifold possibilities for state updating. However, these tools neither provide the functionality for an (semi-)automated process design nor do they support the analysis of interdependencies. Addressing this shortage, (Rueppel and Wagenknecht, 2007) discuss a meta-model mentioning analytical functions (R3) for process adaptation by extending ADEPT. Again, this functionality is mentioned parenthetically and not realized. Nevertheless, it should be noted that, e.g., AristaFlow provides an open API that could principally be used to integrate various software applications in order to connect necessary context information systems (R6) and to provide further functionalities for realizing, e.g., workflow analysis (Lanz, Krehe, Reiche and Dadam, 2010).

A promising approach concerning the development of a DRWfMS can be found in (Sell, 2010; Sell and Braun, 2009). Based on adaptive WfMS, the authors discuss a new layer aiming at determination of feasible process adaptations. Their approach takes context data and several temporal interdependencies into consideration. However, the approach itself considers neither the sources and interpretation of context data nor the selection of appropriate activities (R1) but shifts this issue to an abstract, so-called context service claimed not to be the object of their research. Moreover, the approach only deals with time-related interdependencies and neglects those concerning resources and place (R2).

To conclude the preceding discussion, none of the analyzed approaches takes all identified requirements for a holistic DRWfMS adequately into consideration. In particular, there are no approaches dealing with spatial information and their consideration and formalization in DRP in general. Current projects addressing the use of IS in DRM in the context of EU research, e.g. ORCHESTRA, ARMONIA, or GENESIS (Database, 2013), discuss the development of IS architectures. However, none of these projects focuses either on the use of WfMS as core element of an IS architecture for DRM or the aspired support and monitoring of response activities as well as fast situational adaption of needful actions. Therefore, we describe and discuss a general technical architecture in the following section that could be used as development framework for future holistic DRWfMS.

### A NOVEL INTEGRATED ARCHITECTURE FOR DRWFMS

The DRWfMS architecture proposed in this paper focuses especially on the functional aspects of system parts. As architectures in general, it is discussed on a general level and aims as guidance for system development by providing a framework that should be adaptable to different organizations or levels of DRM. Furthermore, some technical and formal aspects remain open that will have to be answered in future research. An essential precondition for designing/adapting DRP is the integration of relevant and available disaster information from on-site. As depicted in Figure 1, such information is usually provided by external context information providers (1) or, e.g., GIS (2). This implies well-defined communication interfaces data structures, etc. that could be adapted from promising research results, e.g. from standardisation projects like INSPIRE (Database, 2013).

Information from these sources is considered in order to select the initial disaster response activities from a predefined and usually under-specified process repository (3). This might contain single activities and process fragments as well as exhaustive response processes containing, e.g., a description of their applicability and relevance to certain disaster types, demanded alternative resources to carry out the activities, and a specification of basic dependencies between them (e.g. exclusion or prerequisite). Moreover, geo data is also used to analyze potential future threats that might necessitate further response or at least prevention activities. In order to support semi-automated analysis and selection of additional response activities, we propose a disaster rule repository (DRR) (4).This DRR contains the underlying rules specifying basic relations between types of disaster and spatial characteristics as well as basic dependencies between task, resources, and time (e.g. priorities). The specification of what information is of relevance for a certain type of disaster also takes place in the DRR and can consequently be used to identify further information demands. The disaster process analyzer (DPA) (7) is the core of the proposed architecture. It is assigned to both information management (gathering, merging, and processing) and management of process tailoring. This includes, e.g., the analysis and sense-making of data, selection of activities from process repository, determination and proposal of feasible process models under consideration of predefined interdependencies, as well as the management of upcoming process adaptations. Since restrictions and interdependencies might also result from unforeseeable disaster characteristics, an additional interdependence analyzer is proposed as further element. This analyzer deals with additional conditions resulting from spatial characteristics and resource situation on-site. From the system architecture view, the DPA has interfaces to the two repositories, the information sources, and the underlying adaptive WfMS.

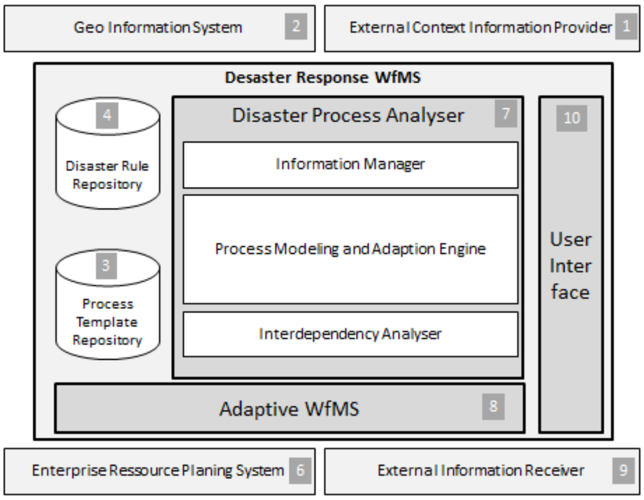


**Figure 1. Integrated architecture for DRWfMS**

Instantiation, execution, and monitoring of parallel DRP are carried out by an adaptive WFMS (8) that provides the flexibility for real-time adaptation of underlying DRP-models determined by the DPA. It is also responsible for information distribution and task delegation to external information receivers (9). Resource allocation can be supported by external systems, e.g. ERP-System (6). Last but not least, the DRWfMS has to provide an appropriate user interface (10) which allows, e.g., the visualization of processes as well as the manual intervention in process planning, analysis, adding further interdependencies and constraints, etc. The user interface is directly connected to the adaptive WfMS (8) but also allows access to the repositories.

To exemplify the interaction of the components, a simplified disaster scenario is used: an explosion occurs and a museum is on fire putting life as well as assets at risk. Disaster response starts with an incoming message containing initial information (kind of disaster, where it happened, etc.). For designing the adequate DRP, this data is captured by the information manager of the DPA (7) supported by the DRR that is searching for additional disaster specific information demands, e.g. from GIS or external information providers (R6). Assuming a rule specifying that structural fires could threaten gas pipes the gas supply has consequently to be turned off. This activity has to be added to the set of appropriate activities so that DPA has to consider available geo data by looking for gas pipes next to the museum. As a first result of the design phase, the DPA's process modeling and adaptation engine in combination with the DRR derives an initial DRP based on the collected information, activities, and process fragments from the process repository (R1 and R3).

Process design in DRM is often restricted due to unforeseeable interdependencies and constraints that have also to be considered. We assume that the initial plan for firefighting schedules a fire engine. If the road was destroyed, an adaptation would be necessary (e.g. rescheduling of a helicopter). To discover such constraints, the interdependency analyzer has to scan geo data (GIS) and to check for further constraints that have to be considered in process tailoring (R2). Before process instantiation can finally be carried out, resource allocation has to be specified with the help of the linked ERP. Here, the feasibility of the tailored DRP might be further constrained due to the resource situation and, hence, might necessitate the DRP to be revised. This iterative planning leads to a suitable DRP that can be instantiated and executed by the adaptive WfMS (R4, R5). The user interface provides information to the DRP managers and allows them to change process features during run-time (R7). The described procedure is not limited to creating new processes, it is also applicable for already on-going DRP.

## CONCLUSION

In this contribution, we argued that DRM can benefit from the application of WfMS; however, we also depicted the demand for a holistic and integrated WfMS. As a major prerequisite for realizing DRWfMS, we see the need for appropriate methods facilitating real-time analysis of interdependencies between activities, resources, places, and time. Without them, an effective planning and management of DRP will not be achievable. Current approaches usually have a more specialized focus and do not take the identified interdependencies adequately into account. Therefore, we propose an extended WfMS architecture for DRM. In order to provide access to spatial information, this architecture includes components for connecting WfMS to GIS as well as a component for real-time analysis of interdependencies with respect to an appropriate adaption of processes in future.

Although research is just at its beginning and not yet evaluated, the case study showed at a general level that the presented architecture is promising and addresses the seven derived requirements for a suitable DRWfMS. As a matter of course, further research is needed: as a next step, components of the architecture have to be specified and developed in more detail. Moreover, interdependencies have to be formalized in order to enable their processing by workflow engines. Furthermore, new algorithms for analyzing interdependencies and deriving possible process adaption have to be developed. This research is seen as a promising basis for the implementation of a prototype DRWfMS that is planned in order to evaluate the effectiveness of the proposed architecture.

## REFERENCES

1. Beroggi, G.E.G. and Wallace, W.A. (1995) Real-Time Decision Support for Emergency Management: An Integration of Advanced Computer and Communications Technology, *Journal of Contingencies and Crisis Management*, 3, 1, 18-26.
2. Chen, R., Sharman, R., Rao, H.R. and Upadhyaya, S. J. (2008) Coordination in emergency response management, *Communications of the ACM*, 51, 66–73. ACM, New York.
3. Dadam, P., Reichert, M. and Rinderle-Ma, S. (2011) Prozessmanagementsysteme. Nur ein wenig Flexibilität wird nicht reichen, *Informatik Spektrum*, 34, 4, 364–376. Springer, Berlin/Heidelberg.
4. Database (2013) Database of projects. http://copernicus.eu/pages-principales/projects/project-database/database-of-projects/?no_cache=1&filter=0&print=1&all=1 (accesd 2013-02-12)
5. Fahland, D. and Woith, H. (2009) Towards process models for disaster response, *Business Process Management Workshops*, 254–265. Springer, Berlin/ Heidelberg.
6. Franke, J., Charoy, F. and Ulmer, C.: A (2010) Model for Temporal Coordination of Disaster Response Activities, *7th Internat. Conf. on IS for Crisis Response and Management*, Seattle, USA.
7. Georgakopoulos, D. (1999) Collaboration process management for advanced applications, *Internat. Process Technology Workshop*, Grenoble, France.
8. Heinrich, B., Klier, M. and Zimmermann, S. (2011) Automatisierte Modellierung, Umsetzung und Ausführung von Prozessen: Ein Web Service-basiertes Konzept, *Proceedings oft the 10th Internat. Wirtschaftsinformatik Conf.*, 1, 88-98. Zürich.
9. Hofmann, M., Sackmann and S., Betke, H. (2013) Using Workflow Management Systems to Improve Disaster Response Processes, *in publication (27th IEEE AINA-2013)*, Barcelona, Spain.
10. Jansen, J.M., Lijnse, B. and Plasmeijer, R. (2010) Towards Dynamic Workflow Support for Crisis Management, *Proceedings of the 7th Internat. ISCRAM Conf.*, 1–5. Seattle, USA.
11. Lanz, A., Kreher, U., Reicher, M. and Dadam, P. (2010) Enabling Process Support for Advanced Applications with the AristaFlow BPM Suite, *Proceedings of the BPM*, 615, New Jersey.

12. Lin, X.Y. and Jun, W. (2008) Context-Driven Business Process Adaptation for Ad Hoc Changes, *Proceedings of the IEEE Internat. Conf. on e-Business Engineering*, 53–60. IEEE Computer Society, Xian.
13. National Research Council (U.S.) (2006) Facing hazards and disasters. Understanding human dimensions, National Academies Press, Washington, D.C.
14. Rueppel, U. and Wagenknecht, A. (2007) Improving emergency management by formal dynamic process-modelling, *24th Conf. on Information Technology in Construction*, 559–564. Maribor, Slovenian.
15. Sell, C. (2010) Systemunterstützung zur automatischen Anpassung von Workflows zur Laufzeit, Dissertation, Technische Universität Dresden, Dresden.
16. Sell, C. and Braun, I. (2009) Using a workflow management system to manage emergency plans, *Proceedings of the 6th Internat. ISCRAM Conf.*, Gothenburg, Sweden.