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# Process-oriented disaster response management: a structured literature review

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## Abstract

**Purpose** – The application of business process methods in the domain of disaster response management (DRM) is seen as promising approach due to the similarity of business processes and disaster response processes at the general structure and goals. But up to now only a few approaches were able to handle the special characteristics of the DRM domain. Thus, the purpose of this paper is to identify the existing approaches and analyze them for the discussion of general requirements for applying methods and tools from business process management to DRM.

**Design/methodology/approach** – A structured literature review covering a wide field of information system-related publications (conferences and journals) is used to identify and classify general requirements discussed as the state of the art.

**Findings** – The work in this paper resulted in a suitable classification of requirements for the development of process-oriented DRM approaches deduced from the existing work. This was used to outline and analyze the current research landscape of this topic and identify research gaps as well as existing limitations.

**Research limitations/implications** – Although the review of the state of the art is based on a wide set of publication databases, there may exist relevant research papers which have not been taken into consideration.

**Originality/value** – The elaborated requirements provide value for both the research community and practitioners. They can be considered to develop new or improve existing DRM systems and, thus, to exploit the potentials of process-oriented IT in supporting DRM in the case of disaster.

**Keywords** Structured literature review, Business process management, Disaster response management, Process-aware information systems

**Paper type** Literature review

## 1. Supporting disaster response management (DRM) with business process management (BPM) approaches

Immediately following a man-made or natural disaster, governmental and aid organizations as well as affected companies initiate disaster response processes (DRPs) as countermeasures. Since the effectiveness and efficiency of DRPs are crucial to restoring the safety of systems, humans, and/or assets as soon as possible, contingency plans and response processes are usually prepared in advance. Whenever a disaster strikes, these plans and processes must be concretized and executed in the phase of disaster response (Rao *et al.*, 2007; Chen *et al.*, 2008; National Research Council (USA), 2006; Turoff *et al.*, 2008).

Aiming at the improvement of DRM and the support of DRP execution, the use of methods from BPM and BPM-related information systems (IS) has been investigated and discussed by several authors (e.g. Fahland and Woith, 2009; Betke and Hofmann, 2014; Rüppel and Wagenknecht, 2007; Sell and Braun, 2009*; Marjanovic and Hallikainen, 2013). As a general result, the introduction of BPM approaches to DRM appears promising since the processes of both domains not only pursue similar goals

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but also show structural similarities, i.e. event-driven processes consisting of activities that rely on resources and actors (Hofmann, 2014). However, a direct application of BPM approaches and related IS to DRM is usually hampered by domain-specific characteristics such as unplannable execution contexts, non-routine/unique processes, sudden and unexpected events, temporal pressure/urgency, uncertain resource situations, involvement of multiple authorities, massive involvement of persons, imperfect information, etc. (Chen *et al.*, 2008; Swenson, 2010; Franke and Charoy, 2010*; Mousavi *et al.*, 2012).

In the literature (see the elaborated overview in the following sections), several approaches have been presented showing both the practical value of BPM to DRM and the resulting domain-specific challenges. However, these approaches are predominantly focused on specific challenges of applying BPM and related IS to the DRM domain. Thus, since a general approach is still missing, the aim of this paper is:

(1) to consolidate the state of the art with respect to applying BPM methods and related IS in the context of DRM;

(2) to identify a catalogue of general requirements for developing further design science artefacts; and

(3) to provide a substantiated basis for further research and development in this field.

As a methodology approach, a comprehensive and structured literature review according to vom Brocke *et al.* (2009) was conducted. Following this method, the remainder of the contribution at hand is structured as follows: according to the applied research methodology, the scope and processing of the literature review is presented in Section 2. Subsequently, Section 3 comprises the findings consisting of a description and analysis of general requirements that have been derived from the literature body. In Section 4, open research issues and desiderata are discussed in order to highlight and foster further research and development activities. The contribution concludes with a short summary.

## 2. Research methodology

Applying BPM methods and related IS successfully in the context of DRM requires an understanding of the domain-specific challenges and resulting requirements that should be adequately taken into consideration in further research and developments in the field. To identify these requirements, the existing body of literature has been analyzed according to the structured literature review method presented in vom Brocke *et al.* (2009). In order to achieve high validity as well as reliability, the conducted literature review procedure is described in the following.

In this context, validity means the degree of accuracy in identifying and handling sources, including a comprehensive selection of scientific databases and search terms. Reliability refers to the replicability of the search process and can be achieved by thoroughly documenting the procedure and by making the selection criteria explicit (vom Brocke *et al.*, 2009). To achieve this basic requirement for a structured literature review and to provide a transparent, comprehensible, and reproducible procedure, the review scope is defined in Section 2.1, and the search terms used are presented in Section 2.2. The search itself, the applied criteria for inclusion, respectively, exclusion of contributions, as well as the applied data extraction and analysis approach, are described in Section 2.3.

### *2.1 Scope of research*

The scope of our literature review is presented according to the literature review taxonomy first proposed in Cooper (1988) and later raised again in vom Brocke *et al.* (2009) (see Table I).

As indicated by the greyed cells of Table I, the presented literature review focuses on existing research outcomes regarding the requirements of a BPM-supported DRM. The main goal is to give a comprehensive overview of relevant research contributions and to identify, respectively, categorize an extensive set of relevant requirements that methods and tools have to fulfil in order to facilitate their application within the domain of DRM. The findings are organized in a conceptual manner and they are presented from a neutral perspective. The target audience of the literature review comprises specialized scholars from the domain of BPM and practitioners concerned with the development of BPM-related support for DRM. In order to take as many relevant research results into consideration as possible, an exhaustive literature search within a multitude of different databases using different search terms has been conducted. The presented findings remain both exhaustive and selective because of the broad spectrum of research contributions.

### *2.2 Conceptualization of the topic*

As second step of a structured literature review, it is recommended to work with key concepts and working definitions about the topic of interest (vom Brocke *et al.*, 2009). Thus, we had to explore the domain of BPM as well as the domain of DRM. A first analysis of domain-specific sources of disaster management made apparent that terminology within this domain is particularly manifold: a first distinction is made between different kinds of disasters, denoted as "emergency", "crisis", "disaster", or "catastrophe". All of these events have in common that they are limited in foreseeability and predictability; are non-routine; occur suddenly; and threaten assets, the functioning of business, or the safety of a system and its elements (Rao *et al.*, 2007; National Research Council (USA), 2006; Turoff *et al.*, 2008).

DRM can thus be seen as a part of a general process of disaster management, which is usually distinguished into the phases of: mitigation, preparedness, response, and recovery. The first two phases deal with vulnerability reduction and preparation for the case of emergency, whereas the latter two phases comprise activities undertaken to counteract a disaster in the immediate aftermath of its occurrence and to restore the pre-disaster state (Rao *et al.*, 2007; Chen *et al.*, 2008; Turoff *et al.*, 2008; Fahland and Woith, 2009). In DRM in particular, an effective, efficient, and flexible process execution is crucial to the safety or even the survival of systems, humans, and/or assets (Rao *et al.*, 2007;

| | Characteristic | Categories | | | |
|---|---|---|---|---|---|
| 1 | Focus | Research outcomes | Research methods | Theories | Applications |
| 2 | Goal | Integration | Criticism | Central issues | |
| 3 | Organisation | Historical | Conceptual | Methodological | |
| 4 | Perspective | Neutral representation | Espousal of position | | |
| 5 | Audience | Specialised scholars | General scholars | Practitioners/ politicians | General public |
| 6 | Coverage | Exhaustive | Exhaustive and selective | Representative | Central/ pivotal |

**Source:** Vom Brocke *et al.* (2009)

**Table I.**
Taxonomy of presented literature review

Turoff *et al.*, 2008; Franke and Charoy, 2010*). In this regard, disaster managers are concerned with coordinating various decentralized and parallel-operated DRPs, i.e. management and execution of response activities, actors, and resources (Chen *et al.*, 2008; Marjanovic and Hallikainen, 2013).

Hence, DRM is seen as a promising field of application for BPM. Based on these insights, we derived the following search terms: "emergency management", "emergency response", "crisis management", "crisis response", "catastrophe management", "catastrophe response", "disaster management", and "disaster response".

On the other hand, BPM can be seen as a superior management concept that deals with the management of business processes, i.e. process-aware management of activities and required resources (e.g. actors, data, material) in order to reach defined business goals (e.g. Weske, 2012). BPM thus provides a plethora of methods and tools, e.g., supporting process design, analysis, and process-oriented execution of activities. In this regard, workflow management systems (WfMS) can be seen as one of the main representatives of BPM tools that support an automated business process execution (Weske, 2012; Dumas *et al.*, 2013).

Hence, to search the area as widely as possible, we decided to use very general keywords: "process aware", "process support", "process oriented", and "workflow". Where the first three terms are intended to discover general BPM-related contributions, the last term allows us to detect technically oriented approaches which deal with WfMS in particular.

### *2.3 Literature search*

The next step of a structured literature review involves the selection of databases, the development of search strategies, and an initial evaluation of the literature. Since considering high-ranked scholarly journals and conference proceedings is recommended (vom Brocke *et al.*, 2009), we decided to search EBSCSOhost, Thomson Reuters Web of Knowledge, Wiley Online Library, ACM Digital Library, IEEE Xplore Digital Library, AIS Electronic Library, Elsevier/Science direct, Emerald, Springerlink, INFORMS, and Palgrave. In addition, we searched *MIS Quarterly* and the *Journal of Management Information Systems* that are not part of the mentioned databases. Furthermore, we used Google Scholar and CiteSeer to identify relevant papers from the International Conference on BPM that are not available at Springerlink and to include domain-specific research contributions within the proceedings of the Information Systems for Crisis Response and Management Conference (ISCRAM) as well as the *International Journal of Information Systems for Crisis Response and Management*.

This set of journals, databases, and conference proceedings allowed a literature search within a broad range of international scientific journals (including the IS basket published by the Association for Information Systems) as well as in high-ranked conference proceedings (e.g. ECIS, ICIS, and AMCIS). The defined set was searched for all contributions that have the identified keywords within their title and/or abstract. Since the aim was to reveal existing research contributions addressing the application of BPM methods and related IS (successfully) in the context of DRM (and not general BPM approaches that might provide further improvement to DRM), we decided to search only for that contributions wherein both topics are discussed jointly. Therefore, keywords from DRM and BPM were combined with the aid of logical operators as follows: ("*emergency management*" OR "*emergency response*" OR "*crisis management*" OR "*crisis response*" OR "*catastrophe management*" OR "*catastrophe response*" OR "*disaster management*" OR "*disaster response*") AND ("*process aware*" OR "*process support*" OR "*process oriented*" OR "*workflow*").

While this query was applied in EBSCSOhost, IEEE Xplore Digital Library, and AIS Electronic Library, it was necessary to adjust it for other databases. For instance, not every search engine provided the functionality to search in title and abstract simultaneously and others did not allow the combination of keywords by multiple logical operators. Thus, simplified search queries were used, e.g. ("*emergency management*" AND ("*process aware*" OR "process support" OR "*process oriented*" OR "workflow")) in Google Scholar, or ("*disaster response*" AND "*workflow*") in Springerlink. The collection of literature ended in October 2013 and resulted in 559 contributions (hits).

As next step of a structured literature review, duplicates, and irrelevant contributions (false positives) were removed from the list of search results by a preliminary screening of titles and abstracts. In particular, we shortlisted research contributions to only such contributions that deal with a process-oriented management of response activities, resources, and/or information flows. We also included contributions that explicitly focus on the applicability of BPM methods and tools within the domain of DRM and/or discuss the requirements and challenges of the domain in a detailed manner. In contrast, we excluded contributions that solely used methods or tools from BPM indirectly to demonstrate the workings of approaches from other research areas (e.g. to demonstrate how agents can help with process-oriented knowledge management in DRM). We also excluded contributions that used DRM only for exemplary application of their research approaches without discussing DRM-related requirements in detail. Applying these criteria for inclusion, respectively, exclusion of contributions resulted in 64 research contributions forming the set for the conducted in-depth analysis. To assure that the set is as complete as possible, we conducted an additional forward and a backward search in order to retrieve previous and later relevant research contributions. The forward search revealed 20 additional relevant contributions while the backward search revealed 14 more. Table II gives an overview of the resulting set of 98 papers.

## 3. Results of structured literature review

As next step of any structured review, the search results have to be analyzed and synthesized (vom Brocke *et al.*, 2009). To conceptualize the findings, we categorize the identified research contributions according to four typical phases of a BPM lifecycle, i.e. process design, process configuration, process enactment, and process evaluation (Weske, 2012). This seems particularly suitable, since a general matching of these phases to the typical phases of DRM, i.e. mitigation, preparedness, response, and recovery, is already discussed and explained in the work of de Leoni *et al.* (2011)*. For example, the process design phase of BPM matches with the preparation phase in DRM where emergency planes are elaborated and modelled.

In order to derive general requirements for using BPM methods and tools in the context of DRM, each single contribution of the identified set of literature was analyzed whether it explicitly identifies, respectively, discusses such requirements, or not. Since different authors use different notations for the same requirement, we extracted the requirements, developed a consistent notation, and related the original requirements accordingly. For each requirement, the results are separately presented in table form: the first column lists the contributions in our set of literature that discuss this particular requirement for the first time and/or with an extensive focus. In the second column, further contributions that also address the requirement but without explicit focus on it are listed. If an author discusses the same requirement(s) in different contributions, only the original

**Table II.** Overview of search results

| Source | Search area | Coverage | Hits | In-depth |
|---|---|---|---|---|
| EBSCSOhost[a] | Title/abstract | 2000- | 3 | 0 |
| Web of Knowledge[b] | Title | 2000- | 2 | 1 |
| Wiley Online Library | Title/abstract | 2000- | 177 | 3 |
| ACM Digital Library | Title/abstract | 2000- | 36 | 14 |
| IEEE Xplore Digital Library | Title/abstract | 2000- | 119 | 11 |
| AIS Electronic Library | All fields and resources | 2000- | 72 | 3 |
| Elsevier/ science direct | Title/abstract/ keywords | 2000- | 8 | 1 |
| Emerald | All except full text | 2000- | 2 | 1 |
| Springerlink | Title/abstract | 2000- | 67 | 5 |
| INFORMS | Throughout | | 7 | 0 |
| Palgrave | Title | 2000- | 0 | 0 |
| *MIS Quarterly* | Basic search | 2000- | 0 | 0 |
| *Journal of Management Information Systems* | Basic search | | 2 | 0 |
| Google scholar | Title | 2000- | 22 | 5 |
| CiteSeer | Title/abstract | 2000- | 24 | 3 |
| BPM Demotracks | Title | 2007- | 2 | 2 |
| ISCRAM Conference Proceedings | Title | 2006- | 15 | 14 |
| *International Journal of Information Systems for Crisis Response and Management* | Title | 2009- | 1 | 1 |
| | Backward | | | 14 |
| | Forward | | | 20 |
| | Sum | | | 98 |

**Notes:** [a]EconLit, Library, Information Science & Technology Abstracts, MLA Directory of Periodicals, MLA International Bibliography. [b]Thomson Reuters, Web of Science

work is listed and marked with an asterisk (*) for easier reading. However, all contributions are listed in an additional appendix-file which is accessible for free at http://tinyurl.com/mguypnl

### *3.1 Process design*

The phase "process design" is usually characterized by the identification and modelling of business processes (Weske, 2012). In the context of DRM, this phase is focused on the planning of effective and efficient countermeasures to a plethora of situations in case of a disaster. Such planning is particularly challenged by uncertainty and bad predictability (Marjanovic and Hallikainen, 2013; Swenson, 2010).

The issue of planning (as good as possible) and its importance for a rapid and effective disaster response is discussed and emphasized in many contributions: during "peacetime", disaster managers have to "define their own process models" (Russo *et al.*, 2012) involving "a set of predefined processes for dealing with various crises and emergencies" (Podorozhny *et al.*, 2008). Pre-defined process models should be stored "in a knowledge base where in case of an emergency the appropriate process can be instantiated" (Ziebermayr *et al.*, 2011). Although such process models are crucial for disaster response, modelling of DRP is usually limited to a general and quite abstract level due to planning uncertainty. Thus, it should also be possible "to model skeletons of processes to be filled during operation based on situation" (Peinel *et al.*, 2012*). Accordingly, the first general requirement is derived as follows: R1 – prepare pre-defined DRP-models, or at least DRP-model fragments (Table III).

**Table III.**
Papers discussing requirement 1

| Originally discussed in: | Foundation of/discussion in: |
|---|---|
| Rüppel and Wagenknecht (2007), Russo *et al.* (2012)*, Ziebermayr *et al.* (2011), Peinel *et al.* (2012)*, Chen *et al.* (2007) | Fahland and Woith (2009), Podorozhny *et al.* (2008), van Someren *et al.* (2005)*, Mak *et al.* (1999), Hofmann *et al.* (2013)*, Tahir *et al.* (2008)*, Fressmann (2006), Shafiq *et al.* (2010)*, Baker *et al.* (1999)*, Delano-Wood *et al.* (2012), Vescoukis and Dulamis (2011), Farnaghi and Mansourian (2013), Ludík and Ráček (2011)*, Mosser *et al.* (2010), Fernandes *et al.* (2006), Lindemann *et al.* (2010), Hoogendoom *et al.* (2005), Wucholt *et al.* (2011), Xin *et al.* (2012), Baird *et al.* (2008), Skogan *et al.* (2004), Weiser and Zipf (2007), Charles *et al.* (2009) |

A second challenge in DRM is the fact that disaster managers are not usually modelling experts and "have problems to understand complex models" (Franke and Charoy, 2010*). Hence "it is necessary to provide an easy understandable language for modelling of disaster management processes" (Ziebermayr *et al.*, 2011). In this regard, Franke and Charoy (2010)* call for BPM methods and tools that "allow simple modeling (i.e. without complex constructs) of the response activities" and that also allow "descriptions of activities in structured and unstructured form" (van Someren *et al.*, 2005*). Moreover, e.g., Rüppel and Wagenknecht (2007) underline the importance of a "comfortable, intuitive visualization of processes", since it "supports the understanding of coherence" in DRP (Moehrle, 2013). Authors in Ziebermayr (2012) go even further and call for a "domain specific, process oriented vocabulary […] which allows modelling the process by domain experts which are not modeling experts". This is also demanded by Peinel *et al.* (2012)*, who discuss a "change of terminology to user-specific 'language'". Accordingly, the second general requirement is derived as follows: (R2) – use modelling languages that are intuitive and easy to understand and that support a graphical visualization (Table IV).

The uncertain nature of disasters often necessitates a resource management that allocates resources "on-the-fly" at DRP runtime. However, "on-the-fly" does not mean unprepared and blind. Rather, it is recommended to pre-specify required materials, roles, actors, and actors' capabilities on an abstract level. Thus, modelling languages "shall allow the modelling of governance roles" (Catarci *et al.*, 2011*) and "capabilities, positions, ranks", etc. (Peinel *et al.*, 2012*). Therewith, the third general requirement is derived as follows: (R3) – use modelling languages that provide modelling elements for DRP-specific roles, actors, resources, capabilities, etc. (Table V).

A further requirement addresses the expressiveness of modelling languages. Since DRPs are usually interweaved with other DRPs, it becomes crucial for DRM to consider dependencies between single processes, e.g. with regard to actors and resources,

**Table IV.**
Papers discussing requirement 2

| Originally discussed in: | Foundation of/discussion in: |
|---|---|
| Rüppel and Wagenknecht (2007), Franke and Charoy (2010)*, Ziebermayr *et al.* (2011), Peinel *et al.* (2012)*, van Someren *et al.* (2005)*, Moehrle (2013), Ziebermayr (2012), Chen *et al.* (2007), Rosa and Mendling (2008) | Russo *et al.* (2012), Shafiq *et al.* (2010)*, Baker *et al.* (1999)*, Delano-Wood *et al.* (2012), Ludík and Ráček (2011)*, Lindemann *et al.* (2010), Skogan *et al.* (2004), Charles *et al.* (2009), Franke *et al.* (2011)* |

dependencies between activities, and time- and place-related restrictions (Sackmann *et al.*, 2013*). Thus, methods and tools of BPM "shall allow the modeling of different kinds of dependencies" (Franke and Charoy, 2010*), e.g. "multiple dependencies" or "unidirectional dependencies" (Sell *et al.*, 2009*). Moreover, disaster managers should be able to "visualize the activities and their dependencies" (Franke *et al.*, 2010*) and to describe them in a detailed manner in order "to automate the handling of related events at runtime" (Sell *et al.*, 2009*). Accordingly, the fourth requirement is derived as follows: R4 – provide modelling languages that support the description and visualization of dependencies (Table VI).

Last but not least, it is necessary to provide methods and tools that support disaster managers in analyzing, simulating, and adapting pre-specified DRPs in advance. For instance, in Russo *et al.* (2012), the authors state that "several offline analyses, aiming at finding out frequent anomalies" should be conducted in order to identify "potential bottlenecks or possible breakdowns […], loopholes and hidden inefficiencies […] which can then be eliminated" (Mak *et al.*, 1999). Accordingly, the fifth requirement is derived as follows: R5 – provide methods and tools for process analysis and simulation at design time (Table VII).

### *3.2 Process configuration*

During process configuration, process models are usually implemented into a business process management system (BPMS), which supports the execution of DRPs (Weske, 2012). However, disaster managers do not usually have the required technical and methodological abilities to transform DRP models into a language that facilitates their automatic processing (Weske, 2012). Thus, a BPMS should provide "an implementation that interprets the disaster management process" (Ziebermayr, 2012), or at least a generic vocabulary "in order to facilitate automatic processing" (Moehrle, 2013). Thus, the sixth general requirement is derived as follows: R6 – provide software tools that are capable of transforming DRP models into executable process specifications (Table VIII).

| Originally discussed in: | Foundation of/discussion in: |
| --- | --- |
| Franke and Charoy (2010)*, Peinel *et al.* (2012)* | Russo *et al.* (2012), Baker *et al.* (1999)*, van Someren *et al.* (2005)*, Ludík and Ráček (2011)*, Lindemann *et al.* (2010), Franke *et al.* (2011)*, Charles *et al.* (2009) |

**Table V.** Papers discussing requirement 3

| Originally discussed in: | Foundation of/discussion in: |
| --- | --- |
| Sell *et al.* (2009)*, Franke *et al.* (2010)*, Hausmann *et al.* (2012) | Baker *et al.* (1999)*, Hofmann *et al.* (2013)*, Chen *et al.* (2007), Franke *et al.* (2011)* |

**Table VI.** Papers discussing requirement 4

| Originally discussed in: | Foundation of/discussion in: |
| --- | --- |
| Russo *et al.* (2012), Mak *et al.* (1999) | Peinel *et al.* (2012)*, Sackmann *et al.* (2013)*, Vescoukis and Dulamis (2011) |

**Table VII.** Papers discussing requirement 5

To facilitate a context-aware process execution, a BPMS should provide various interfaces with DRM-relevant IS and information technology. This is crucial to DRM, "since new information might influence decisions about alternative available response strategies or even goals and priorities in general" (Hofmann *et al.*, 2013*). Hence, a BPMS has to grant access to disaster relevant information and to provide "an overview on the crisis and its evolution" (Tahir *et al.*, 2008*). For instance, (Catarci *et al.*, 2011*) call for an integration of Geographic Information Systems, "which allow users to gain a deep knowledge of the area". Moreover, context awareness is of particular importance in order to determine necessary DRP adaptations and "to calculate and execute the workflow adaptations" (Sell and Springer, 2009*). Accordingly, the seventh general requirement is derived as follows: R7 – provide interfaces that support real-time integration of incoming information from various information sources (Table IX).

Moreover, "[c]ommunication and collaboration support is crucial" (Russo *et al.*, 2012) in DRM, since "persons from […] various emergency-response organizations collaborate with each other to achieve a common goal" (Catarci *et al.*, 2011*). Thus on the one hand, BPMSs need a robust communication infrastructure "to provide information at any location the mobile worker can be" (Fressmann, 2006). On the other hand, "it is advisable to opt for Mobile Networks" (Catarci *et al.*, 2011*) and "to use mobile devices and wireless communication" (de Leoni *et al.*, 2011*). Furthermore, BPMSs should "nurture cooperation, collaboration and partnership formation" (Jul, 2007), offering "shared activity workspaces" (Franke and Charoy, 2010*) and giving "access to the crisis model and views on it to Partners" (Tahir *et al.*, 2008*). Accordingly, the eighth general requirement is derived as follows: R8 – provide functionalities for (inter-organizational) communication and collaboration between responders and crisis centres (Table X).

Last but not least, a further requirement regards the usability of BPMSs, which should be as intuitive as possible, because "people involved in response and recovery actions are experts in their domain but not information technology" (Rosa and Mendling, 2008). Hence, a BPMS should be "extremely usable and intuitive" (Catarci *et al.*, 2011*) and "self-explanatory" (Rosa and Mendling, 2008), and should "seek to support just-in-time learning" (Jul, 2007). Accordingly, the ninth general requirement is as follows: R9 – provide a BPMS that is easy to learn and intuitive to handle (Table XI).

**Table VIII.**
Papers discussing requirement 6

| Originally discussed in: | Foundation of/discussion in: |
| --- | --- |
| Ziebermayr *et al.* (2011), Moehrle (2013), Ziebermayr (2012) | Skogan *et al.* (2004) |

**Table IX.**
Papers discussing requirement 7

| Originally discussed in: | Foundation of/discussion in: |
| --- | --- |
| Russo *et al.* (2012), van Someren *et al.* (2005)*, Hofmann *et al.* (2013)*, Tahir *et al.* (2008)*, Fressmann (2006), Hausmann *et al.* (2012), Catarci *et al.* (2011)*, Sell and Springer (2009)*, Jul (2007), Jansen *et al.* (2010)* | Mak *et al.* (1999), Shafiq *et al.* (2010)*, Baker *et al.* (1999)*, Farnaghi and Mansourian (2013), Ludík and Ráček (2011)*, Skogan *et al.* (2004), Weiser and Zipf (2007), Riedel and Chaves (2012), van Diggelen *et al.* (2008) |

### 3.3 Process enactment

Within the phase of process enactment, BPMSs are usually used to manage and coordinate the execution of manual and/or (semi-)automated business process activities. In this regard, identified requirements can be categorized into two areas: requirements related to DRP coordination and requirements related to a flexible execution of response activities.

*3.3.1 Coordination.* To ensure an purposeful, effective, and efficient process execution, it is necessary to coordinate and to guide the interplay between activities, resources and required information at process runtime. For instance, relevant information need to be forwarded and activities need to be assigned to executing actors. Consequently, one key requirement of DRM is "to provide support for coordinating emergency operators" (de Leoni *et al.*, 2011*) and, in particular, to support "the coordination of the activities of the actors that intervene in the crisis resolution" (Tahir *et al.*, 2008*). Accordingly, the tenth general requirement can be seen as a meta-requirement, and is derived as follows: R10 – support the overall coordination of disaster response in an integrated manner. However, the literature review revealed that coordination concerns different areas, resulting in different requirements: the management of resources and actors, response activities, and information flows (Table XII).

Resource management in DRM includes "the listing of required resources, the requesting and ordering process, as well as its allocation to an activity" (Sell and Braun, 2009*), since actors and "scoped roles cannot be populated a priori; they must be dynamically created and removed as needed by the process" (Baker *et al.*, 1999) during

| Originally discussed in: | Foundation of/discussion in: |
|---|---|
| Fahland and Woith (2009), Franke and Charoy (2010)*, Russo *et al.* (2012), Peinel *et al.* (2012)*, Chen *et al.* (2007), Hofmann *et al.* (2013)*,Tahir *et al.* (2008)*, Fressmann (2006), Baker *et al.* (1999)*, Catarci *et al.* (2011)*, Jul (2007), Jansen *et al.* (2010)* | Podorozhny *et al.* (2008), Vescoukis and Dulamis (2011), Farnaghi and Mansourian (2013), Hoogendoom *et al.* (2005), Wucholt *et al.* (2011), Xin *et al.* (2012), Franke *et al.* (2011)*, van Diggelen *et al.* (2008), Poulymenopoulou *et al.* (2003) |

**Table X.** Papers discussing requirement 8

| Originally discussed in: | Foundation of/discussion in: |
|---|---|
| Peinel *et al.* (2012)*, Fressmann (2006), Rosa and Mendling (2008), Catarci *et al.* (2011)*, Jul (2007), Jansen *et al.* (2010)*, Wang *et al.* (2007)* | Franke and Charoy (2010)*, van Someren *et al.* (2005)* |

**Table XI.** Papers discussing requirement 9

| Originally discussed in: | Foundation of/discussion in: |
|---|---|
| Fahland and Woith (2009), Chen *et al.* (2007), Hofmann *et al.* (2013)*, Tahir *et al.* (2008)*, Jul (2007), Jansen *et al.* (2010)* | Franke and Charoy (2010)*, Russo *et al.* (2012), Podorozhny *et al.* (2008), van Someren *et al.* (2005)*, Mak *et al.* (1999), Baker *et al.* (1999)* (Catarci *et al.* (2011)* |

**Table XII.** Papers discussing requirement 10 runtime of a DRP. Thus "additional contextual or historical information may be considered for resource selection" (de Leoni *et al.*, 2011*). Because of time criticality in DRM, authors in de Leoni *et al.* (2011)* state that "it is preferable to use a push-based approach, where the [BPMS] dynamically selects a resource qualified for executing a given task". This also implies that tool support for "identifying the resource requirements for each response activity and the agencies that can provide the needed resources" (Shafiq *et al.*, 2010*) is required. Hence, the 11th general requirement is derived as follows: R11 – Provide methods and tools to support on-the-fly resource management (Table XIII).

In regard to task management, a BPMS must support task delegation (e.g. de Leoni *et al.*, 2011* and Sell and Braun, 2009*) and "orchestration of the dynamic [DRP]" (Tahir *et al.*, 2008*). Therefore, response activities should be determined and suggested by a BPMS (e.g. Moehrle, 2013) and automatically delegated to on-site responders who are responsible for their execution (Sell and Braun, 2009*). Hence, the 12th general requirement is derived as follows: R12 – provide methods and tools to support dynamic task management and task delegation (Table XIV).

Another crucial requirement for BPMSs concerns support for information management and the coordination of information flows, since DRM is confronted with information overload (e.g. Mak *et al.*, 1999) and a "large amount of information sources that occur in different forms, e.g. structured and unstructured data" (Fressmann, 2006). Thus, BPMS "should determine which actor needs to know which information at what time and only provide the actors with information that is relevant to their task at that moment" (van Someren *et al.*, 2005*). Therefore, "a dynamic task allocation tool" is required (van Someren *et al.*, 2005*), one that provides "reliable information" (Tahir *et al.*, 2008*) to responders "so that they can make timely and informed decisions" (Baker *et al.*, 1999*). This must be ensured even "when actors change roles, take on new tasks, and abandon old tasks" (van Someren *et al.*, 2005*). Moreover, for better information management, information load and information flow should be monitored and documented (van Someren *et al.*, 2005*). Hence, the 13th general requirement is derived as follows: R13 – provide methods and tools for information management (Table XV).

**Table XIII.**
Papers discussing requirement 11

| Originally discussed in: | Foundation of/discussion in: |
|---|---|
| Fahland and Woith (2009), Sell and Braun (2009)*, Russo *et al.* (2012), Ziebermayr *et al.* (2011), Peinel *et al.* (2012)*, Chen *et al.* (2007), Hofmann *et al.* (2013)*, Tahir *et al.* (2008)*, Baker *et al.* (1999)*, Jul (2007), Jansen *et al.* (2010)* | Shafiq *et al.* (2010)*, Wang *et al.* (2007)*, Reijers *et al.* (2007) |

**Table XIV.**
Papers discussing requirement 12

| Originally discussed in: | Foundation of/discussion in: |
|---|---|
| Sell and Braun (2009)*, Russo *et al.* (2012), Ziebermayr *et al.* (2011), van Someren *et al.* (2005)*, Moehrle (2013), Ziebermayr (2012), Chen *et al.* (2007), Hofmann *et al.* (2013)*, Tahir *et al.* (2008)*, Fressmann (2006), Rosa and Mendling (2008), Sell and Springer (2009)* | Fahland and Woith (2009), Mak *et al.* (1999), Baker *et al.* (1999)*, Vescoukis and Dulamis (2011), Catarci *et al.* (2011)*, Riedel and Chaves (2012), Reijers *et al.* (2007) |

Within the coordination areas mentioned above, "there is a need for quick and efficient decision making" (Rosa and Mendling, 2008), since human lives and assets are at risk. Thus, "continuous evaluation at run time" (Podorozhny *et al.*, 2008) of DRP is required, and decision making should be supported by "decision analysis techniques, multiple criteria methods, expert systems and decision support technologies" (Mak *et al.*, 1999). For instance, providing disaster managers with best practices and information about past experiences (e.g. Moehrle, 2013; Fressmann, 2006) that might influence their decisions is recommended. In addition, disaster managers should be supported, e.g. when "choosing the appropriate process in case of disaster" (Ziebermayr, 2012) or "in case of alternative routes" (Sell and Braun, 2009*). Hence, "intelligent recommendation techniques and decision making schemes able to dynamically select the most salient disaster management plans" (Vescoukis and Dulamis, 2011) should be integrated into BPMSs. Additionally, simulation techniques depict "a very important aspect for evaluating the efficiency of a natural disaster implementation plan" (Vescoukis and Dulamis, 2011) and can be used to analyze the "likely development of the scenario" (Hausmann *et al.*, 2012) so that "the consequences of possible actions" (Tahir *et al.*, 2008*) can be considered during the decision-making process. Hence, the 14th general requirement is derived as follows: R14 – provide methods and tools for runtime analysis and simulation of DRPs (Table XVI).

*3.3.2 Flexible process execution.* The literature review revealed that BPMSs can also be used in the domain of DRM to "support the execution of [response] activities" (Franke and Charoy, 2010*) so that "after the completion of an activity automatically the next pending activity/activities is/are highlighted for the staff" (Sell and Braun, 2009*). As responsibilities are triggered and executed automatically, the DRP has to be "encoded as a dynamic process and executed" by a BPMS. However, a main difference between BPM and DRM concerns the uncertain and dynamic realities of disasters, which "call for dynamic and flexible tools" (Farnaghi and Mansourian, 2013) that are "flexible enough to accommodate the variation in the crisis response that can occur" (Baker *et al.*, 1999*). Accordingly, the 15th general requirement is derived as follows: R15 – provide BPMSs that support a flexible execution of DRPs (Table XVII).

In particular, flexibility refers to the "possibility to dynamically change predefined processes" (Rüppel and Wagenknecht, 2007) at the runtime of a disaster. Therefore, a BPMS should support the "dynamic adaptation of the process" (Riedel and Chaves, 2012)

| Originally discussed in: | Foundation of/discussion in: |
|---|---|
| van Someren *et al.* (2005)*, Chen *et al.* (2007), Hofmann *et al.* (2013)*, Fressmann (2006), Baker *et al.* (1999)* | (Tahir *et al.*, 2008)* (Mak *et al.*, 1999) (Farnaghi and Mansourian, 2013), (Ludík and Ráček, 2011)*, (Lindemann *et al.*, 2010), (van Diggelen *et al.*, 2008) |

**Table XV.** Papers discussing requirement 13

| Originally discussed in: | Foundation of/discussion in: |
|---|---|
| Podorozhny *et al.* (2008), Mak *et al.* (1999), Hofmann *et al.* (2013)*, Vescoukis and Dulamis (2011), Hausmann *et al.* (2012), Catarci *et al.* (2011)* | – |

**Table XVI.** Papers discussing requirement 14 and provide functionalities for the "addition of new activities, modifications/changes (reassignment, rescheduling) of the planned activities, and removal of one or more of the activities" (Shafiq *et al.*, 2010*) from pre-planned DRPs. In this regard, the literature review revealed different approaches for realizing the required flexibility, e.g. by "large process specifications that are specialized time by time according to the specific happenings" (Catarci *et al.*, 2011*) and DRP models that "can be designed on-demand from provided templates and configurable models" (de Leoni *et al.*, 2011*). However, because of the "time-sensitive nature of disaster response, manual service composition [and process adaptation] is not a feasible solution" (Farnaghi and Mansourian, 2013). Hence, e.g. de Leoni *et al.* (2011)* and Sell and Springer (2009)* call for an (semi-)automated and context-aware process adaptation, e.g. by means of reassignment of "given task[s] to another resource" (de Leoni *et al.*, 2011*) or automated calculation and suggestion of structural process model adaptations (Sell and Springer, 2009*). Accordingly, the 16th general requirement is derived as follows: R16 – provide methods and tools that support manual as well as (semi-)automated process adaptation at runtime (Table XVIII).

Furthermore, a BPMS has to provide detailed information about DRP progress and "state change of activities" (Franke and Charoy, 2010*) in order to trigger runtime adaptations "when exogenous events turn […] [DRP instances into something] unsuccessful" (de Leoni *et al.*, 2008*). Therefore, a "continuous monitoring to detect discrepancies" (de Leoni *et al.*, 2007*) is required. For instance, according to de Leoni *et al.* (2011), status information about "process schema, running tasks, resources, and team members' status and capabilities" can be "used to desizedine which adaptation patterns should be applied to restructure the running process". Thus, the 17th general requirement is derived as follows: R17 – provide detailed information on current activity and resource states as well as the progress of DRPs (Table XIX).

| Originally discussed in: | Foundation of/discussion in: |
| --- | --- |
| Fahland and Woith (2009), Rüppel and Wagenknecht (2007), Sell and Braun (2009)*, Franke and Charoy (2010)*, Ziebermayr *et al.* (2011), Peinel *et al.* (2012)*, Chen *et al.* (2007), Hofmann *et al.* (2013)*, Tahir *et al.* (2008)*, Baker *et al.* (1999)*, Rosa and Mendling (2008), Hausmann *et al.* (2012), Jul (2007), Jansen *et al.* (2010)*, Wang *et al.* (2007)* | Russo *et al.* (2012), Podorozhny *et al.* (2008), Delano-Wood *et al.* (2012), Vescoukis and Dulamis (2011), Farnaghi and Mansourian (2013), Ludík and Ráček (2011)*, Baird *et al.* (2008), Skogan *et al.* (2004), Catarci *et al.* (2011)*, Poulymenopoulou *et al.* (2003), Lanz *et al.* (2010), Llavador *et al.* (2006) |

**Table XVII.**
Papers discussing requirement 15

| Originally discussed in: | Foundation of/discussion in: |
| --- | --- |
| Swenson (2010), Russo *et al.* (2012), Chen *et al.* (2007), Catarci *et al.* (2011)*, Sell and Springer (2009)* | Fahland and Woith (2009), Podorozhny *et al.* (2008), Hofmann *et al.* (2013)*, Tahir *et al.* (2008)*, Fressmann (2006), Shafiq *et al.* (2010)*, Baker *et al.* (1999)*, Delano-Wood *et al.* (2012), Vescoukis and Dulamis (2011), Farnaghi and Mansourian (2013), Mosser *et al.* (2010), Fernandes *et al.* (2006), Xin *et al.* (2012), Baird *et al.* (2008), Skogan *et al.* (2004), Hausmann *et al.* (2012), Riedel and Chaves (2012), Wang *et al.* (2007)*, Llavador *et al.* (2006) |

**Table XVIII.**
Papers discussing requirement 16

However, runtime adaptation of DRP might be error prone (regardless of whether DRPs are implemented manually or (semi-)automatically). Thus, "on-the-fly verification of the correctness of the modified workflow" (Wang *et al.*, 2007*) is required in order to guarantee an error-free DRP execution. In addition, even state changes of an activity "may violate dependencies" (Franke and Charoy, 2010*) so that "interdependencies of the activities and the execution state of the workflow" (Sell and Springer, 2009*) have to be considered and verified when adapting DRPs. Accordingly, the 18th general requirement is derived as follows: R18 – provide tools for syntactic validation and correctness verification of DRPs (Table XX).

Since it must be assumed that many users of BPMSs are technically inexperienced, adaptation logic should be kept simple and should facilitate an easy and swift implementation of process adaptations (Sell and Springer, 2009*; Rosa and Mendling, 2008). For instance, according to Sell and Springer (2009)*, "it has to be simple to delete and add new [context information], to change the mapping of [context information] on workflow adaptations and to change the interdependencies of the activities". Thus, the 19th general requirement is derived as follows: R19 – keep adaptation logic as simple as possible (Table XXI).

### *3.4 Process evaluation*

Within process evaluation, executed business processes are re-evaluated (e.g. in regard to effectiveness and efficiency) for future process improvement (Weske, 2012). Authors in Moehrle (2013) state that even in DRM "performance analysis has to be included" (Moehrle, 2013) so that the "fulfilment of goals and objectives" (Peinel *et al.*, 2012*) can be analyzed and "previous plans from pre-disaster for preparedness can be adjusted (learned lessons)" (Hofmann *et al.*, 2013*). Therefore, DRP executions should be "recorded in the form of process logs" (de Leoni *et al.*, 2011*) and analyzed after execution. For instance, "[p]rocess mining techniques can be adopted during peacetime

| Originally discussed in: | Foundation of/discussion in: |
|---|---|
| Rüppel and Wagenknecht (2007), Sell and Braun (2009)*, Franke and Charoy (2010)*, Russo *et al.* (2012), Chen *et al.* (2007), Hofmann *et al.* (2013)*, Sell and Springer (2009)* | Fahland and Woith (2009), van Someren *et al.* (2005)*, Shafiq *et al.* (2010)*, Baker *et al.* (1999)*, Delano-Wood *et al.* (2012), Franke *et al.* (2011)*, Wang *et al.* (2007)* |

**Table XIX.** Papers discussing requirement 17

| Originally discussed in: | Foundation of/discussion in: |
|---|---|
| Franke and Charoy (2010)*, Sell and Springer (2009)*, Wang *et al.* (2007)* | Fahland and Woith (2009), Hofmann *et al.* (2013)*, Franke *et al.* (2011)*, Hausmann *et al.* (2012), Kittel *et al.* (2013) |

**Table XX.** Papers discussing requirement 18

| Originally discussed in: | Foundation of/discussion in: |
|---|---|
| Sell and Springer (2009)* | Baker *et al.* (1999)*, Rosa and Mendling (2008), Wang *et al.* (2007)* |

**Table XXI.** Papers discussing requirement 19 to identify anomalies and typical collaboration patterns in emergency scenarios" and to identify "new and optimized versions of procedures/processes [that] can be defined to be more effective and adhere to the real world" (Russo *et al.*, 2012). Hence, the 20th general requirement is derived as follows: R20 – support process evaluation and improvement by appropriate analysis and evaluation methods (Table XXII).

For later process evaluation and improvement, it is necessary to compare initial and actually executed DRP. Hence, it is necessary to store terminated processes (Rüppel and Wagenknecht, 2007) and to document "changes to the process instance" (Ziebermayr *et al.*, 2011). Accordingly, the 21st general requirement is derived as follows: R21 – document process adaptations for later process evaluation (Table XXIII).

Concluding our literature review, the examined literature body reveals 21 general requirements for using BPM methods and tools in the field of DRM.

## 4. Research landscape and further discussion of results

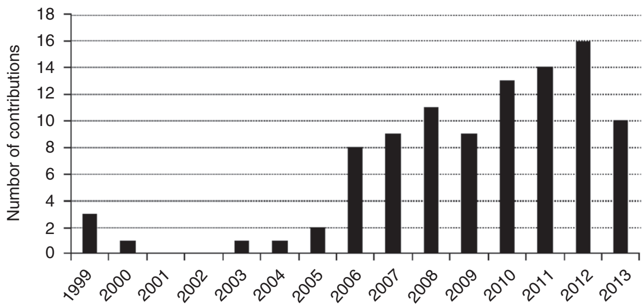
The conducted literature review does not only reveal the extensive catalogue of general requirements for using BPM methods and tools in the field of DRM. It also showed that the requirements differ significantly from the typical BPM domain, thus calling for domain-specific research and development. The continuously rising number of publications that can be observed (see Figure 1) suggests an increasing attention to this field in research and development.

**Table XXII.** Papers discussing requirement 20

| Originally discussed in: | Foundation of/discussion in: |
|---|---|
| Peinel *et al.* (2012)*, Moehrle (2013), Chen *et al.* (2007), Hofmann *et al.* (2013)* | Russo *et al.* (2012), Podorozhny *et al.* (2008), Vescoukis and Dulamis (2011), Charles *et al.* (2009), Franke *et al.* (2011)* |

**Table XXIII.** Papers discussing requirement 21

| Originally discussed in: | Foundation of/discussion in: |
|---|---|
| Rüppel and Wagenknecht (2007), Ziebermayr *et al.* (2011), Ziebermayr (2012) | – |




**Note:** Please note that 2013 is only taken into consideration until October

**Figure 1.** Distribution of articles by year of publication

An additional analysis of the identified literature with regard to the current research focus clearly shows that not all requirements are actually addressed yet. The literature review revealed a multitude of research approaches already addressing the development of flexible BPMSs (R15) and methods that support a (semi-)automated adaptation at runtime of the DRPs (R16). Therefore, it is not surprising that most of the identified research contributions aim to support the overall coordination of response activities (R10) and the delegation of tasks (R12). Moreover, there seems to be a consensus that BPMSs in DRM should support communication (R8) as well as real-time integration of incoming information from various information sources, i.e. by providing interfaces for several DRM-related IS and technologies (R7). In addition, a large number of research approaches postulate pre-specified DRPs or at least DRP skeletons that can be filled in during DRP runtime.

However, our literature review also revealed that several requirements are underexposed. For instance, one research gap involves the expressiveness of current modelling languages, which usually do not provide DRM-related elements for, e.g., specifying resources (R3) and dependencies (R4). Although this is a crucial requirement in DRM, only a few research contributions can be found that are concerned with this open issue. Similarly, there are only a few contributions that provide methods and tools for process analysis and simulation at design time. Another noticeable research gap can be found between the phases of process design and process enactment. Whereas on the one hand, pre-specifying DRPs requires intuitive and easy to understand modelling languages (R2), on the other hand, process enactment is based on process specifications that are executable. Hence, there is demand for software tools that can transform DRP models into executable process specifications (R6). However, only a few research groups have contributed to the resolution of this open issue. Even information and resource management (R11 and R13) during process enactment are underexposed, as they are not yet integrated in a satisfactory form. Although the requirements are mentioned repeatedly, only a few research groups actually deal with this topic. Another research gap regards the adaptation of DRPs at runtime. Although the infeasibility of a manual process adaptation is mentioned several times, there are only a few research groups that develop methods and tools that support process adaptation in a comprehensive manner, i.e. by providing methods and tools for runtime analysis and simulation of DRPs (R14), for suggesting semantically correct DRP adaptations (R16), for providing a simple adaptation logic (R19), and for proving the correctness of DRP adaptations (R18). Last but not least, it is clear that the evaluation phase is out of research focus (R20, R21), although this area implies a huge potential for future DRP improvements.

In summary, it can be stated that, up to now, no scientific approach has addressed the aforementioned requirements in a comprehensive manner; rather approaches uniformly focus on selected general requirements. However, in order to make BPM methods and tools applicable and to facilitate the utilization of their potentials in DRM, such a comprehensive view is required. As indicated by the research landscape, there is a multitude of research possibilities.

## 5. Conclusion and outlook

Applying BPM methods and BPM-related IS to improve disaster management has been discussed for several years. Although existing research results and first experiences are very promising, only a few of the developed approaches have found their way into practice so far. This gap motivated our research to identify requirements that are beyond general requirements of disaster management and that are specific for exploiting the potentials provided by BPM approaches in the future more effectively. Hence, a priority objective of this contribution was to identify, merge, and classify such relevant requirements.

As a methodical basis, we used a comprehensive, exhaustive, and structured literature review dating back to 1999, which covers 98 mainly scientific contributions addressing the issue. The appendix of this paper (accessible at: http://tinyurl.com/mguypnl) contains an overview and description of all identified research projects and their assigned papers. The presented catalogue of requirements resulting from the analyzed approaches and body of literature, thus, provides a general state of the art for future development and research. Although the elaborated catalogue of requirements is not claimed to be complete and might alter with further research progress. The results should be taken into consideration when designing and developing novel BPM-related research approaches in order to create applicable tools and methods for DRM. Furthermore, the identified requirements can also serve for checking existing BPM systems in the domain of disaster management in regard to improvement needs.

Last but not least, the research landscape presented in Section 4 provides detailed insights into current research gaps, and points out a multitude of research opportunities and desiderata for the interested research community as well as practitioners. It is not really surprising that missing methods and tools require a wider focus than the one on automation and integration that has been predominate in the domain of BPM for many years. Current BPM trends with regard to big data analysis, business intelligence, and adaptive business processes can be expected to also push the usability of BPM systems in the field of DRM. The prospect on reflecting analysis results in real-time and accordingly adapting process instances "on the fly" promises advances and progress with respect to several of the sketched research fields above.

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## Further reading

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