Using Precedence Diagram Method in Process-Oriented Disaster Response Management

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ABSTRACT

When planning and modeling disaster response processes (DRP), the unpredictability of disasters precludes accounting for all eventualities in advance. DRPs are thus typically concretized and adapted after the disaster and during the process's run-time. Since time is critical and uncertainty typical, planning of DRPs requires methods and tools that support disaster managers in process analysis, process adaptation, and decision making. This contribution presents an approach for identifying concurrent activities that, in needing identical resources at the same time in different locations, are jeopardized by such place-related conflicts. As solution, the approach allows managers to calculate valid execution sequences, eliminate place-related conflicts, and prioritize activities by total execution time. Results are shown to form a novel, reliable basis for contributing to disaster managers' decision support.

Keywords: Disaster response management, disaster response processes, disaster logistics, precedence diagram method, process adaptation

PROCESS-ORIENTED DISASTER RESPONSE MANAGEMENT

Disasters caused either by humans (e.g., accidents, terrorist attacks) or natural phenomena (e.g., earthquakes, hurricanes) (Chen et al., 2008; National Research Council, 2006) threaten assets as well as human lives. To ensure an effective response should disaster strike, contingency plans are usually prepared in advance to guide disaster response managers (DRM) immediately after the disaster hits. Based on those plans, DRMs initialize and coordinate a variety of disaster response processes (DRP) (Bölsche, 2009; Tomasini and Wassenhove, 2009).

The chief challenges for DRMs follow from the inherent unpredictability of disasters and thus DRMs reduced ability to form fully appropriate plans. Regarding the coordination of resources (e.g., staff, helpers, materials), a principal challenge is ensuring resource availability at DRP places of execution, for the actual locations of response activity cannot be planned. In the immediate aftermath of a disaster occurrence, DRMs thus have to continually analyze all operating DRPs in light of such resource bottlenecks, as well as to adapt them with the additional transport activities to bring required resources from their storage location to DRP places of execution (Hofmann et al., 2015a; Rao et al., 2007).

An initial IT-based approach for supporting DRMs with identifying and resolving place-related resource conflicts automatically is the DRP-ADAPT method (Hofmann et al., 2015b). DRP-ADAPT is based on process graphs consisting of response activities specified by an (abstract) place of execution and resources needed. To identify activities without physical resource availability at their places of execution, DRP-ADAPT determines the last known place of resource usage, which it compares with the actual (subsequent) place of execution (for details, see (Hofmann et al., 2015b)). As a result, each identified place-related conflict is resolved by inserting a concurrent transport activity automatically in ongoing DRPs. Figure 1a illustrates the method, in which the activities "Preparing emergency vehicle" and "Building up shelters" of an (oversimplified) DRP require both the resource "emergency generator." Since the places of execution of both activities differ (operation center ≠ disaster region), DRP-ADAPT identifies it as place-related conflict, which it resolves by adding a transport activity (Figure 1b).

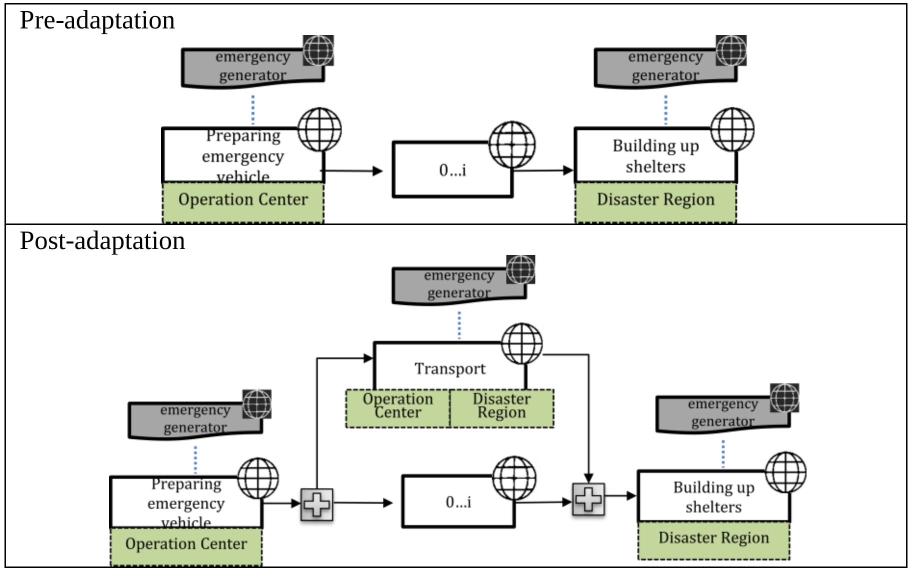

Figure 1. a) DRP with a place-related conflict and b) its solution by adaptation

However, the capability of DRP-ADAPT quickly reaches its limits. If concurrent activities (AND branch) compete for a non-dividable resource, then resource conflicts cannot be resolved only on the basis of an underlying graph structure (Betke et al., 2014). Since physical resources can be exactly at one place at the same, the subsequent execution of activities linked by a transport activity is inevitable. This inevitability results in alternative execution traces (resp. activity sequences) within a DRP, of which only one can be executed.

To exemplify the problem, we have prepared the following exemplary DRP (Figure 2) that, though oversimplified, is suitable for didactic reasons. This DRP consists of eight activities, two of which ("Set up first aid station" and "Support firefighting") compete for the non-dividable resource "head of operations." In Figure 2, the two arrows represent the existing alternative traces that require a transport activity. However, that activity's places of origin and delivery depend on which alternative is chosen during run-time. As such, a resolution of the conflict is indeterminable without knowing the actual execution sequence.

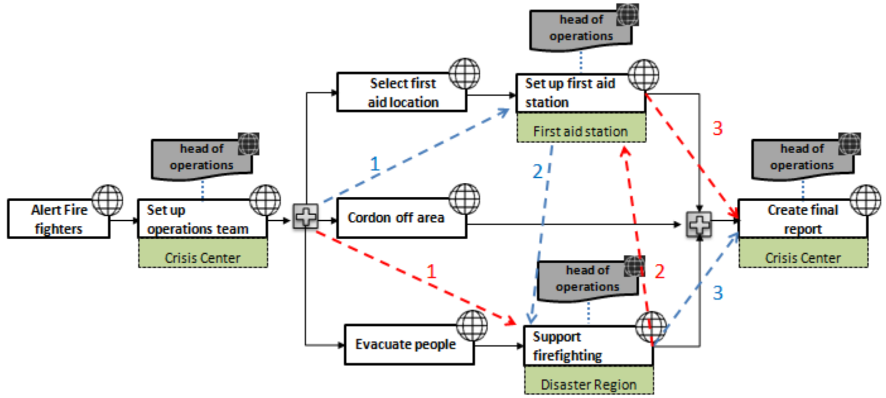

Figure 2. Concurrent activities and possible execution sequences

Hofmann (2014) solves this planning problem by under-specification, in which transport activities with several places of origin are inserted and the DRM has to manually choose an appropriate execution trace manually during run-time. Thus, all required transport activities must be initialized one after another. With an increasing number of AND branches, activities, and/or resources, it becomes increasingly challenging to determine an ideal or even valid execution trace within a reasonable time with only the naked eye.

To close this gap, an extension of the DRP-ADAPT has been developed based on the precedence diagram method that identifies valid and time-optimal execution traces for concurrent activities posing place-related conflicts. As a result, DRM decision making is supported by a list of valid execution alternatives ranked according to total execution time. It is assumed that such information at hand might prevent poor decisions and save valuable time. The remainder of this paper discusses the approach for resolving place-related conflicts posed by concurrent activities.

USING THE PRECEDENCE DIAGRAM METHOD TO EXTEND DRP-ADAPT

The precedence diagram method is well-known in scheduling activities within projects. With this method, projects are described as activity-on-node network (ANN) diagrams consisting of time-consuming activity nodes and directed edges specifying the execution sequences. Based on an activity's duration, the precedence diagram method allows users to calculate the minimum project execution time and buffer times during which concurrent activities can be postponed without delaying the whole project (e.g., Rosenkranz, 2002).

Since DRPs are similar to extended ANN diagrams—both consist of activity nodes and directed edges (Betke et al., 2014)—the precedence diagram method can be used for determining the duration of alternative execution traces within a DRP and for calculating the best trace within AND branches. Yet, to obtain these results, it is necessary to estimate the duration of single response and transport activities at least within AND branches. The approach thus takes the following four steps: (1) transferring DRP into ANN diagrams, (2) identifying place-related resource conflicts, (3) modeling and integrating transport activities (i.e., adaptation), and (4) recalculating the total duration of adapted ANN diagrams and build the ranking.

Transferring DRP into ANN diagrams

A DRP can be described as the directed graph DRP = (A,E,R,PO,PD), which consists of a set of activities $A = \{a_1, . . . , a_n\}$ and a set of directed edges $E = \{(a_1,a_2), . . . , (a_{n-1},a_n)\}$ that specify their temporal sequence. For each activity, it is specified which resources $R = \{r_1, . . . , r_n\}$ are required for execution, at what place of origin (PO) it will be executed or started, and for transport activities, where its place of delivery (PD) is.

To transfer an AND branch of a DRP into an ANN diagram, each activity and connecting edge between the control flow operators parallel split and join has to be transferred (van der Aalst et al., 2003). The direct predecessor and successor are adopted as the start respecting the end node of the ANN diagram subgraph. Control flow operators do not have to be adopted, since every branch is interpreted as a logical AND in ANN diagrams. Moreover, for each activity node, the required resources, as well as their place of origin and place of delivery, are noted in the property fields (Figure 3). In the case that resources and/or places are not specified, these fields remain empty.

The basic structure of activity nodes is extended by fields specifying time-related properties: duration (D), earliest start and end dates (ESD/EED), latest start and end dates (LSD/LED), and the buffer (B), all of which are of special relevance to our research. The duration of a response activity represents the time from its start to end and must be estimated by experts considering the realities of the disaster. The buffer represents the time that can be used to postpone activities without delaying the execution of the AND branch. The buffer and both, the earliest and latest start and end dates, are then calculated by applying the precedence diagram method (e.g., Rosenkranz, 2002).

To illustrate, the exemplary DRP from Figure 2 has been transferred to an ANN diagram (Figure 3) consisting of seven activity nodes, five of which are located on parallel branches. The start and end nodes of the ANN diagram ("Set up operations team" and "Create final report"), as well as the parallel activities "Set up first aid station" and "Support firefighting," require the resource "head of operations." The duration of activities was chosen for its exemplarity, and the (theoretical) minimal execution time is calculated as 50 units, derived from the earliest end date of the end node.

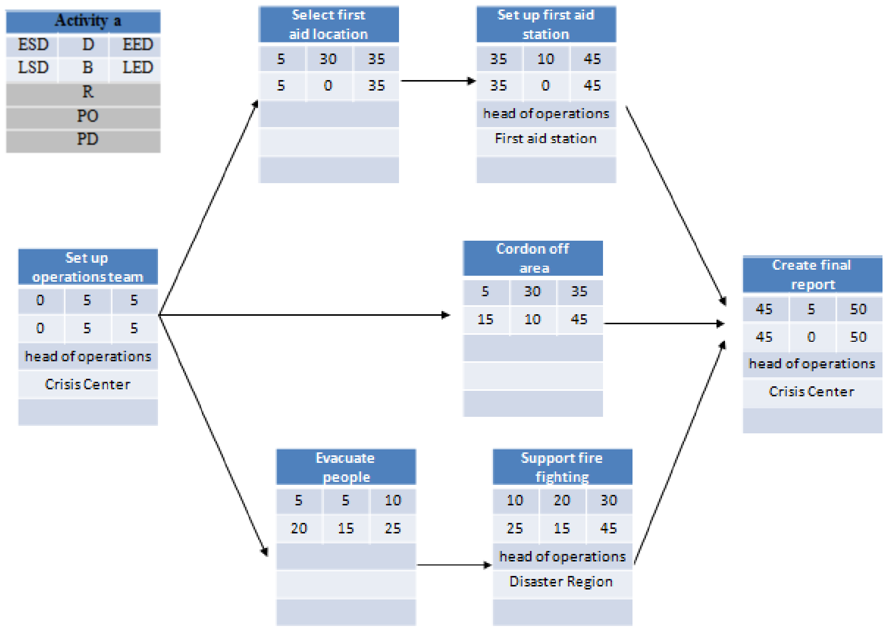

Figure 3. An ANN-diagram for an exemplary DRP

Analyzing resource conflicts and specifying transport activities

As a second step, the ANN diagram is analyzed to identify place-related conflicts of resource use. As Betke et al. (2014) have described, such conflicts arise whenever the place of execution of a resource-related activity differs from the place of execution of a subsequent resource-related activity. Since within an AND branch the execution sequence is not defined, identifying sequence-derived conflicts is not possible. To solve this problem, all possible business process variants (e.g., Sadiq, 2007) can be captured by neglecting the directed edges within the AND branch and performing forward-and-backward graph traversal (Hofmann et al., 2015a). For the ANN diagram presented in Figure 3, two resource-related execution traces can be identified:

Step	Sequence 1	Sequence 2
1st	Set up operations team	Create final report
2nd	Set up first aid station	Support fire fighting
3rd.	Support fire fighting	Set up first aid station
4rd	Create final report	Create final report

Table 1. Execution traces for an exemplary DRP

For each trace, place-related conflicts can be unambiguously determined by directly comparing places of execution of the predecessor and successor. As such, it also becomes possible for single traces to resolve the conflict by integrating clearly specified transport activities that prevent the DRP from becoming stuck. The place of origin can be derived from the predecessor's place of execution and the place of delivery from the successor's place of execution. The duration of the transport activity can then be determined, for instance, with the aid of route planning systems by calculating the travel time between the place of origin and delivery. For example, sequence S_1 has been analyzed regarding place-related conflicts and appropriate transport activities, as outlined in Table 2.

Predecessor - Successor	Result of the comparison	Transport activity	Duration (D)
Set up operations team / Set up first aid station	Crisis Center != First aid station	TA_1, Place of origin: Crisis Center, Place of delivery: First aid station	15
Set up first aid station / Support fire fighting	First aid station != Disaster region	TA_2, Place of origin: First aid station, Place of delivery: Disaster region	5
Support fire fighting / Create final report	Disaster region != Crisis-Center	TA_3, Place of origin: Disaster region Place of delivery: Crisis Center	10

Table 2. Place-related conflicts in sequence S_1 used to solve transport activities

Integrating transport activities and (re)calculating the ANN diagram

To identify the best execution trace in total and provide a basis for their ranking, the ANN diagram must be accordingly adapted and recalculated for each valid alternative sequence. To specify the temporal sequence of a trace within the ANN diagram without changing the general graph structure, so called sequence edges known in business process modeling (e.g., Reichert, 2000) are introduced. These edges allow the general integration method of transport activities presented, for example, in Hofmann (2014) to remain applicable, since transport activities can still be integrated path-wise and concurrently between place-related predecessors and successors. Sequence edges are drawn between a response activity and concurrent subsequent transport activity (see the dotted arrow in Figure 4). In doing so, it must be ensured that sequence edges are directed edges connecting predecessor and successor activities to thereby determine the earliest start date and latest end date of activity nodes.

An ANN diagram modified in this way can be easily recalculated to determine the minimal execution time by adequately taking the required transport activities for conflict resolution into consideration. To illustrate, the modified ANN diagram for sequence S_1 is shown in Figure 4 and recalculated. The ANN diagram thus consists of 10 activities, three of which are (new) transport activities TA_1, TA2, and TA3. The activity "Set up first aid station" is connected to TA_2 by a sequence edge, and the minimum project execution time is calculated to be 85 units. Recalculating the minimum project execution time for all alternative execution sequences within the AND branch thus allows users to easily find the targeted ranking of valid execution paths.

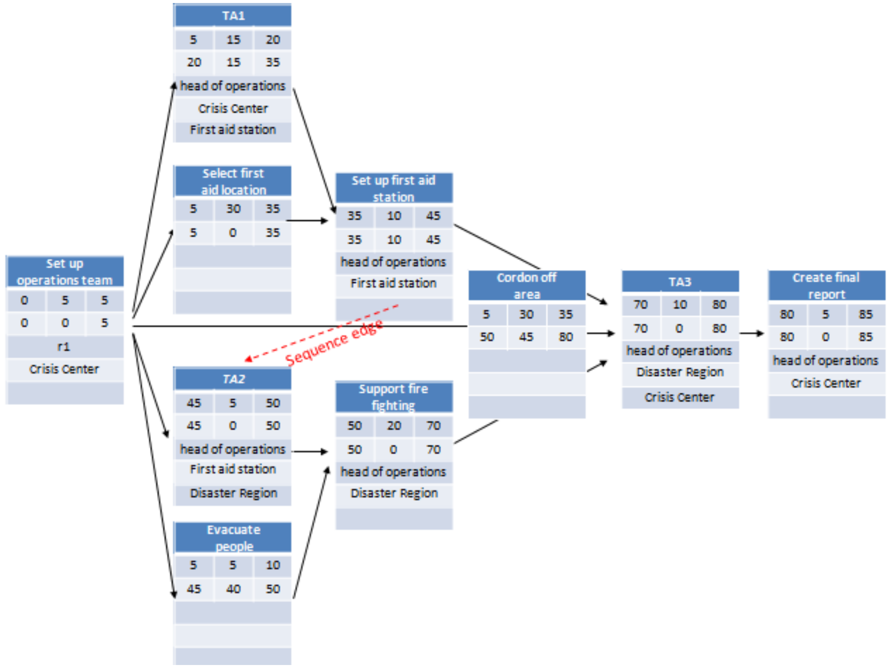

Figure 4. Adapted ANN for sequence S_1

CONCLUSION AND FUTURE DEVELOPMENT

In this contribution, an extension to DRP-ADAPT has been presented that aims to support of decision making of DRMs by generating a list of valid execution traaces ranked by total execution time. First, the method identifies place-related resource conflicts within an AND branch of a DRP by analyzing all resource-related execution traces with the DRP-ADAPT algorithm. Second, all identified conflicts are resolved for each trace individually by inserting adequate transport activities. Third, the precedence diagram method is used to calculate the theoretical execution time for each alternative execution trace and to rank them. Results can ultimately be presented to DRMs, who become able to choose the actual execution trace from alternatives free from place-related resource conflicts and calculated regarding their (estimated) execution time.

Current disaster response workflow management systems (DRWfMS) (Hofmann et al. 2015b) might provide a sound tool for realizing the targeted decision-making support. Based on real-time information from places of execution and durations of transport activities, calculating time-optimal execution traces might be a valuable improvement. Since focusing on time optimization only could neglect a plethora of other relevant aims in DRM (e.g., with lives endangered, it might be better to not choose the fastest execution trace), it is advisable not to execute the adaptation automatically but to instead use the DRWfMS for presenting and selecting the best alternative. However, if several alternatives exist, the calculated order might provide valuable decision support. The integration of our method in DRWfMS provides further benefits, since it allows the continuous monitoring of the disaster and could thus be used to allow the continuous identification of place-related conflicts and the calculation of execution times. Such prospects suggest a promising basis for integrating further improvements in process adaptation. For instance, if the available timespan for disaster response falls below a calculated execution time (e.g., when a nuclear plant is on fire and there is only limited time to shut down the reactor), alternative and faster transport activities and/or resources might be identified as possible solutions (e.g., using helicopters instead of vehicles to fly in experts).

Following the design science approach (Hevner et al., 2004), we plan to overcome these shortcomings with further research cycles. In addressing such a multifaceted goal, we are currently enhancing the presented method with the integration and application of the analytic hierarchy process method to allow the consideration of additional priorities. Addressing the limited focus on only one (indivisible) resource, in future research we will extend the underlying resource model (Betke, 2015). To improve the determination of the execution time of single response activities, which usually must be estimated by experts during DRP execution and cannot be determined before a disaster strikes, we plan to develop a scenario-based prognosis tool. By reducing the uncertainty resulting from vague estimations, the analysis could be enhanced by using expected values to calculate different scenarios (e.g., worst, best, and average). However, all of these improvements would not change the general approach presented in this contribution.

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