DECISION SUPPORT FOR CRISIS MANAGEMENT BY LARGE-SCALE EXERCISES

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Abstract

Natural disasters with a subsequent power blackout can cause serious damages in complex economic nets (such as water supply infrastructure or food supply networks) as well as in social systems (e.g. medical care structures). In the event of such large scale emergencies, a coherent and effective emergency management involving complex decisions and fast realisation of appropriate countermeasures is necessary. The aim of this study is to develop a decision support system (DSS) for crisis management in the event of large area blackouts. Multi-Criteria Decision Analysis (MCDA) can help to involve the different parties (e.g. all relevant administrative levels) in the decision making process in a transparent way and to bring together the knowledge from diverse disciplines. In Order to support and speed up the problem structuring process within MCDA, it is proposed to use Case-based reasoning (CBR). CBR is a methodology from the field of artificial intelligence, in which new problems can be solved by adapting solutions that were successful in previous problems.

In this study we present an approach for combining MCDA and CBR in a decision support system for crisis management. The application and creation of a case base is described in the context of a case study which is based on data from the first cross-national emergency management exercise LÜKEX ("Länderübergreifende Katastrophenschutz Exercise"), which was conducted by the Federal Office of Civil Protection and Disaster Assistance in four Federal States of Germany.

1 Introduction

Emergency situations can differ in many ways, for instance, according to their causes and the dimension of their impact. Yet, emergency situations share the characteristic of sudden onset and the necessity for a coherent and effective emergency management involving complex decisions under time pressure and the need for prompt and efficient reactions from the responsible persons (Geldermann et al., 2007). Often, effects of man-made or natural hazards are propagated through complex economic nets (e.g. supply chains such as electricity supply networks or food supply chains) or

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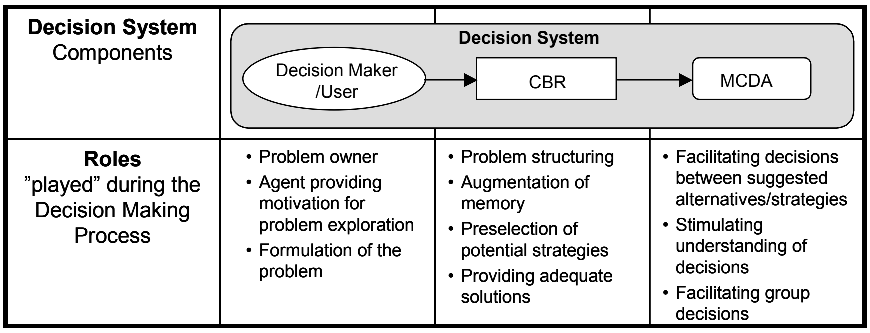
social systems (e.g. medical care structures). For instance, in the event of a large area power blackout, the subsequent impacts and the extent of damages to society and economy as a whole can be severe but predictions are afflicted with uncertainties.
To asses these impacts, the first cross-national crisis management exercise LÜKEX was conducted in 2004 by the Federal Office of Civil Protection and Disaster Assistance in four Federal States of Germany (approx. 29 million inhabitants, area of 120.000 km^2). During this three day exercise, a scenario involving a large area blackout in the south of Germany due to thunderstorms and heavy snowfall was assumed (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe, 2004).
In order to facilitate the complex decision processes in the event of such a large area blackout, decision support is needed. The aim of the study presented in this paper is to develop a decision support system (DSS) for power outages resulting from bad weather conditions, based on the data obtained from the LÜKEX exercise as well as on expert knowledge.
The resolution of complex decision situations in crisis and emergency management following a man-made or natural emergency usually requires input from different disciplines and fields of expertise. Since this involves resolving many conflicting objectives, setting priorities, and perhaps most importantly, bringing the various perspectives of the many stakeholder groups into some form of consensus, multi-criteria decision analysis (MCDA) can help to bring together existing knowledge and to ensure transparency during the decision making process (Geldermann, 2006; Belton and Stewart, 2002; French, 2000; Hämäläinen et al., 2000).
Since the consequences in large scale crises are relatively unpredictable, a structuring and preselection of alternative emergency countermeasures tailored to the actual situation are necessary. For that purpose and to provide richer support for decision making, case-based reasoning methods (CBR) from the field of artificial intelligence can be integrated in DSSs (Dutta et al., 1997; Kolodner, 1993). In CBR systems, new problems are solved by adapting solutions that were used to solve previous problems (Aamodt and Plaza, 1994). For example, experiences and data from the conducted crisis management exercise can be used for decision support in case of an emergency. A possible combination of CBR and MCDA is shown in Figure 1. The implementation of CBR helps the decision makers to structure the knowledge about potential alternative emergency strategies and countermeasures. Thus, it acts to augment the decision makers memory about alternatives and helps to provide potential problem solutions for the person to consider that he or she might not be aware of (Kolodner, 1993).

Figure 1: Decision System integrating CBR (adapted from Angehrn and Dutta, 1992)

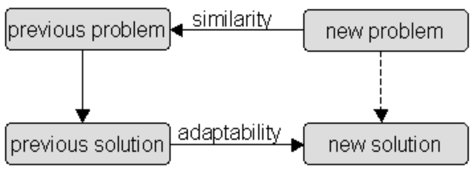


In this paper, the possibility of integrating CBR methods as an approach for problem structuring and preselection in DSSs for crisis management is examined. In Section 2 the foundations of conventional CBR are explained, while Section 3 describes a possible combination of CBR and MCDA as well as parallels between the two methods in a DSS. In Section 4, the structuring of data reported from the LÜKEX exercise as well as the subsequent implementation of a CBR system are presented. The last section concludes the paper by highlighting the contributions of this paper and describing challenges for further research.

2 CBR methodology

Case-based reasoning is a methodology from the field of artificial intelligence. As opposed to rule-based reasoning, where rule chains are given as explanations, CBR uses specific encapsulated prior experiences as a basis for reasoning about new situations (Watson, 1997). In CBR, new problems are solved by adapting solutions that were used to solve previous problems (Kolodner, 1993; Riesbeck and Schank, 1989) (cf. Figure 2). The methodology of CBR has its roots in the field of cognitive sciences. It is adapted from humans` intelligence as people in their daily life often revert back to solutions of previous problems in order to manage new situations. (Ross, 1989; Ross, 1986) for example has shown that people, when learning to solve problems, often refer back to previous problems in order to find suitable solutions in their memories. Also experts seem to have a preference for using cases in problem solving or decision making (Kinley, 2001), but they do not always remember the right ones (Gentner, 1989). This problem is alleviated and memories of experts are augmented by using computers as a retrieval tool (Kolodner, 1993).

Figure 2: Problem solving with CBR (Minor, 2006)



In CBR-Systems, previous cases are stored in a case library (CL). A case typically is a record comprising a problem description (state of the world when the case occurred) and the description of the corresponding solution (Watson, 1997). CBR applications are implemented for different domains and task types. The domain can for example be mechanical engineering, medicine, business administration or crisis management. Different task types in CBR for example are diagnosis, configuration or planning (Richter, 1998). The size of the CL highly depends on the domain and task types being addressed. In some CBR systems, only a few cases are required for an appropriate performance while in others hundreds or even thousands of cases need to be stored in the CL (Leake, 1996).
A fundamental issue in building a CBR-System is choosing the appropriate representation of cases in the CL (Aamodt and Plaza, 1994). The case representation is highly influenced by the domain and the task type of a CBR-System. The main data structures that occur in CBR are the traditional data structures also used in database technology (Richter and Aamodt, 2006). In literature, several different approaches to case representation and, related to that, different techniques for case-based reasoning can be found:

- textual CBR (cases are represented in free text form) (Minor, 2006)
- conversational CBR (cases are lists of questions and answers) (Johnson, 2000)
- structural CBR (cases are stored according to preselected measurable attributes (e.g. names, values like cost and temperature) (Price and Pegler, 1995).

Since attributes of cases are often costly to determine or sometimes simply unavailable, the possibility to match cases on partial information within CBR is essential (Bogaerts and Leake, 2004). The classical CBR process on a conceptual level is represented by the CBR cycle. The main phases of the CBR action are the steps *retrieve, reuse, revise* and *retain* (Aamodt and Plaza, 1994).
During the *retrieval*, the most similar case or a set of similar cases for an actual problem in the CL are determined. The retrieval is based on a measure of similarity between the current situation and the stored case (Wilson, 2001). The process of remembering relevant cases relies heavily upon the used similarity metric. A typically used method for the similarity assessment in CBR is the method of nearest neighbour (Richter, 1998; Watson, 1997; Watson

and Marir, 1994). In this approach, the similarity between two cases is based on matching a weighted sum of features/attributes where the weight expresses the relative importance of a feature. The determination of weights is often one of the biggest problems in similarity assessment. A typical *evaluation function* (also called global similarity function) often used for nearest neighbour matching is given by (Kolodner, 1993):

(1) $$\frac{\sum_{i=1}^{n} w_i * sim\left(a_i^I, a_i^R\right)}{\sum_{i=1}^{n} w_i}$$

with:

w_i Weight (importance) of attribute I; $\in [0,1]$
sim Similarity function; $\in R^2 \rightarrow [0,1]$
a_i^I Value of attribute a_i of input case; $\in$ R
a_i^R Value of attribute a_i of retrieved case; $\in$ R

Both *weights* and dimension of the *local similarity function*, sim(f_i^I, f_i^R) are represented as values between 0 and 1. Closer matches have values close to 1, poorer matches closer to 0. After a case has been retrieved successfully, the next step is to *reuse* and apply the matched case to the new problem. The simplest way of reuse is to transfer the unchanged solution of the old problem to the actual problem. However, in many applications (e.g. planning) this is not possible and even small differences may require significant modification (case adaptation). The case adaptation is performed in the *revision* step. The flexibility of problem solving of CBR systems highly depends on the ability of the system to adapt retrieved cases to new circumstances and on the ability to repair solutions which failed (Leake, 1996). As case adaptation requires additional background knowledge, it is usually performed by user intervention or static rules. In order to overcome the difficulties in case adaptation and to automate this process, (Leake et al., 1997) and (Kinley, 2001) developed a CBR system whose components themselves use CBR for case adaptation.

The adapted cases are stored in the CL in the *retain* step. This provides the mechanism for the system to augment its knowledge and to learn from the problems that have been solved. However, it must be kept in mind that a large CL must be well organised in order to avoid elongation of retrieval time.

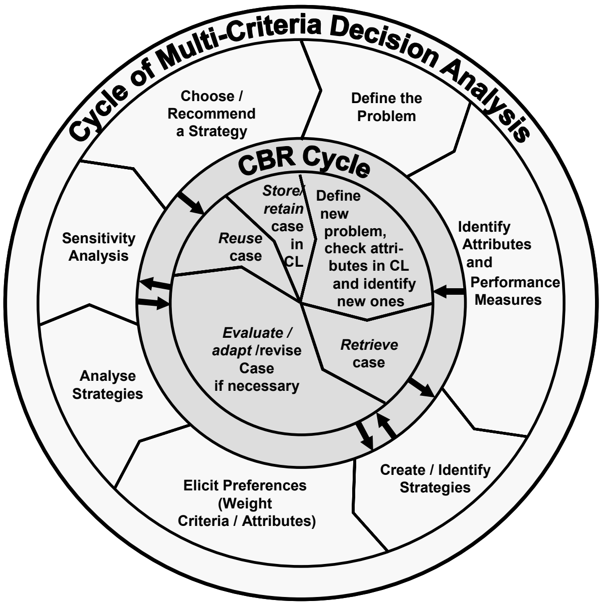
CBR systems have been implemented successfully in the last two decades for several domains and tasks: for diagnosis (Bareiss, 1989), help desks (Lenz et al., 2007), electronic commerce (Stolpmann and Wess, 1998) as well as process design (Price and Pegler, 1995). Furthermore, CBR is used for planning issues. In the late eighties (Goodman, 1989) implemented a CBR system for strategic war planning. In DIAL, a textual CBR system for disaster response planning, the components themselves use CBR for both similarity assessment during a plan retrieval and the adaptation of the retrieved plans (Kinley, 2001; Leake et al., 1997). Other CBR applications in the field of disaster response planning are e.g. the decision support system called CHARADE which is used for forest fire management in Italy (Avesani et al., 2000) and the Interactive Crisis Assistant (INCA) applied to the domain of handling hazardous materials (Gervasio et al., 1998).

In most of the systems using CBR, the user/expert is actively involved in the decision process. Thus, CBR-Systems enable the active participation of experts in complex decisions instead of trying to automate solution finding which was the original intention of knowledge based systems (Wess, 1996). The facilitation and further support of decision processes by means of problem structuring and preselection of potential solutions was the intention of the integration of CBR methods in a DSS using MCDA. In the next section, the combination and parallels of these two methods are explained in more detail.

3 Combining CBR and MCDA

Decisions in the context of emergency management involve many parties who usually have different views, responsibilities and interests (Geldermann et al., 2007; French and Geldermann, 2005). Multi-Criteria Decision Analysis (MCDA), as one method within the field of operations research, can help to involve the different parties in the decision making process in a transparent way and to bring together their knowledge from diverse disciplines. One field of research within MCDA, which has proven suitable for application in the scope of emergency management (see Geldermann et al., 2007; Hämäläinen et al., 2000; French, 1996), is multi-attribute value theory (MAVT). This theory provides methods to structure and analyse decision problems by means of attribute trees and to elicit the relative importance of criteria in such a tree. In short, the essential interactive steps of a MAVT analysis are problem structuring, preference elicitation, aggregation, sensitivity analysis and finally the decision (or a recommendation), each of which is often done in a moderated/facilitated discussion. Problem structuring is a very important part within MAVT which is concerned with appropriately formulating rather than solving a problem (Belton and Stewart, 2002). It gives a better understanding of both, the problem and the values affecting a decision and also serves as a basis for further analyses and as a common language for communication (Shaw et al., 2004; Rosenhead and Mingers, 2001).
However, in large-scale emergencies, problem structuring can become a very challenging task and usual problem structuring approaches might possibly fail. Thus, it is proposed to support and speed up the problem structuring process by using CBR methods for a "preselection" of potential strategies based on past experiences and knowledge. In addition, such an amalgamation of CBR and MCDA could contribute to interactive learning which is often not supported by common DSSs. In this context, learning should be understood in a symbiotic, bidirectional way: users can learn from a DSS about (stored) prior problem solutions and the DSS can learn from users by observing their problem solving behaviours (Angehrn and Dutta, 1992). Figure 3 shows the parallels between the cycles of MCDA and CBR and how CBR could be integrated into the MCDA cycle. Both methods are mutually beneficial.

Figure 3: Cycles of MCDA and CBR



In order to harmonise the terminologies of CBR and MCDA, the wording in the depicted CBR Cycle deviates in a few points from the classical CBR cycle described in the previous section. Since in combination with MCDA, the CBR methods are used for structuring and preselection of possible solutions, we introduced an evaluation step. Here, all proposed cases are evaluated if they are adequate solutions and if they qualify as suitable strategies.

Furthermore, we think that it is useful in the context of decision making in crisis management to set the reuse step behind the evaluation and adaptation process (the revise step in the classical CBR cycle) because CBR methods are only used for a preselection of possible strategies and a modification before application would be necessary in most cases.
Besides finding the most applicable countermeasure strategies in different situations, MCDA can help to enhance public confidence and understanding as well as transparency and traceability in relation to emergency management. Without such trust building components, decisions might not be accepted by the public and the potential benefit of a decision might double back to negative results. It should be emphasised that any multi-criteria decision support system is not intended to substitute but to assist decision makers in resolving complex decision situations (see e.g. Bertsch et al., 2006) and that MCDA as well as CBR – especially in the adaptation/revision phase – necessitate input of the persons in charge and thus actively strive to involve them in the decision making process.

4 Implementation of CBR in a DSS for crisis management

The first national crisis management exercise in Germany, LÜKEX, was conducted by the Federal Office of Civil Protection and Disaster Assistance in four Federal States in 2004. During this exercise, 6000 participants from administration, police and industry practiced how to deal with arising threats caused by natural hazards and the consequential damages. Besides the four Federal States (Bavaria, Baden-Wuerttemberg, Berlin and Schleswig-Holstein) and eight Federal Ministries, 100 external actors, such as, for example, power producers, meteorological service, telecommunication companies, discounters and German Railway were involved in the exercise. During the three day exercise, a scenario was assumed involving a large area blackout in the south of Germany due to thunderstorms and heavy snowfall. The main aim of this simulation exercise was to examine the reactivity to a trans-sectoral crisis in a large area.
The scenario and the course of the exercise was distributed to the participating departments in the form of screenplays, which had been elaborated in more than 100 workshops in preparation for the exercise. The responding operations and consequences of a blackout as well as the proposed reactions of the different departments have been documented in a protocol data base. The exercise has already been analysed in terms of strategic and administrative aspects (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe, 2004). The aim of this study now, is a further evaluation of the LÜKEX exercise considering consequential arising threats and the development of a decision support system for large area blackouts. Since large scale exercises like LÜKEX are conducted in order to be prepared for arising future crises, the gained knowledge should be available for future decisions. Thus, in order to use these experiences for decision support in crisis management, a CBR system based on the protocol data is implemented and integrated in a DSS. In the domain of crisis management, CBR should be preferred to rule-based reasoning, because consequences of disasters are often unpredictable, reported data (e.g. from exercises or previous disasters) can be incomplete and no algorithms for evaluation might be available (Kolodner, 1993). Another major advantage of CBR systems is the fact that they allow the decision maker to propose problems and corresponding solutions very quickly, eliminating the time necessary to develop them from scratch. This time saving aspect is essential in crisis management as, in the event of a crisis, complex decision making often takes place under time pressure. In CBR, problems and solutions which failed can also be integrated, this can be a useful warning, helping the decision maker to take actions to avoid repeating past or potential mistakes. Altogether, CBR seems to be a promising method which is suited for implementation in the decision process in crisis management. It facilitates the preselection of potential emergency countermeasures and problem solutions, because it helps to focus on important parts of a problem by pointing out the important attributes. In building an efficient CBR system, it is essential to find an appropriate representation of cases in the CL (Aamodt and Plaza, 1994). Therefore, relevant, discriminating and measurable features/attributes of the problems and the related solutions must be determined (Watson, 1997).

From the received protocol data, it can be seen that direct damages to critical infrastructures like power supply chains can lead to serious consequential problems in various sectors. Some selected sectors typically affected by long-time power blackouts are listed in Table 1.
Since in the protocol database, all arising problems are stored together, a structuring of the protocol data is necessary before building a case base. The reported data in the protocol data base are classified according to the affected sector (also called domain) and provided with a domain specific key. In total, 18 different domains were identified from the data base. In this section, the data structuring and case base (CL) creation for the health care sector are exemplarily described.

Table 1: Sectors affected by long-time power outages

Domain - Affected Sector	Entity
Direct electricity use	- Industry - Households
Agriculture and food supply	- Milk industry - Livestock farming - Slaughterhouses - Food industries
Medical care	- Hospitals - Nursing homes
Water Supply/waste management/environment	- Water supply - Waste disposal - Handling hazardous materials
Communication and information systems	- Telephone - Internet - Data processing
Transport	- Rail/air/road - Long-distance transport - Local traffic
Emergency and crisis management	- Emergency medical services - Public safety - Administration

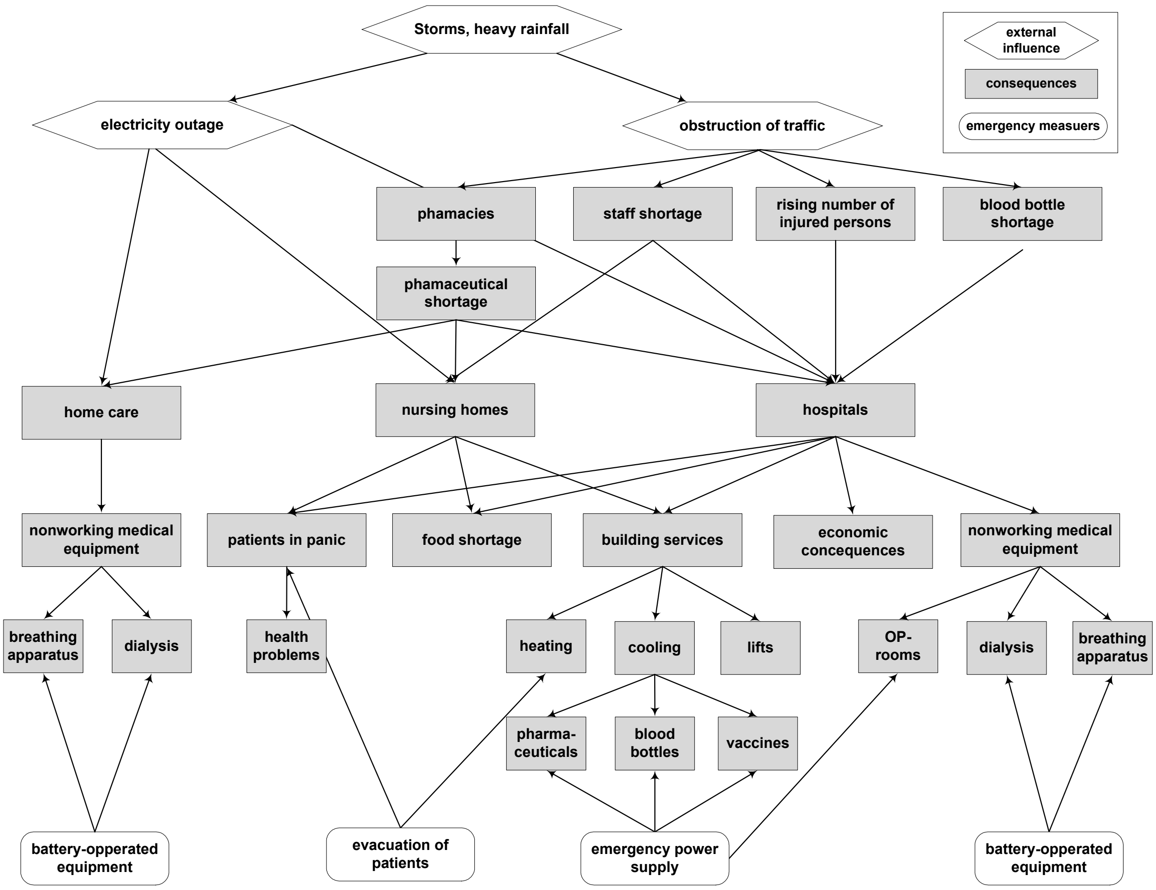
For the structuring of data within each domain, the consequences of a power blackout in combination with bad weather conditions are described (see Figure 4). From this selection, typical representative cases of the domain are identified.
As already mentioned above one of the major challenges in building a case base is the appropriate selection of relevant and measurable attributes for the case representation. For the domain of health care the following attributes/features could be identified:

- duration of blackout
- number of affected persons
- number of affected persons seriously injured
- distance to the next hospital not affected
- range of emergency power supply
- number of missing staff
- range of pharmaceuticals
- amount of missing pharmaceuticals
- number of blood bottles available
- economic losses

Because of the high heterogeneity of the different affected domains, it is impossible to find a case representation with uniform attributes which is appropriate for cases from all domains. Therefore, we suggest to create 18 different case bases, one for each domain. These case bases in the end can be linked again in the DSS. (Leake and Sooriamurthi, 2001) pointed out that in the case of different case representations, retaining multiple case-bases can benefit both performance and maintenance of CLs. However, in order to achieve those benefits it is

inevitable to develop methods for case-dispatching (deciding which case-base to select) and for cross-case adaptation (revising proposed solutions to apply them in another context).
At this point it has to be mentioned that the data in the protocol database of the LÜKEX exercise is not sufficient for the development of a complete CL for a decision support system for large area blackouts. For a more detailed and complete case representation, additional information is necessary, thus experts need to be interviewed and future exercises need to be conducted. But at least it helps to evaluate the immense data already available, to structure it and to document it in a reasonable way. Reuse for future exercises is also possible.

Figure 4: Consequences of a power blackout in the health care sector



5 Discussion and Conclusion

In the event of large scale emergencies like natural disasters with a subsequent power blackout, a coherent and effective emergency management involving complex decisions and fast realisation of appropriate countermeasures is necessary. The selection of efficient countermeasures and reaction strategies usually requires knowledge and input from different disciplines and fields of expertise. In this paper we presented a conceptual approach for decision support in the field of crisis management which combines methodologies from MCDA and CBR: Here the CBR helps the user to structure the knowledge about possible solutions to planning problems and acts to augment the decision makers memory about appropriate strategies in the event of crises. It should be pointed out that any DSS is not intended to automate the decision process nor to substitute the user. Rather it can fasten and facilitate the decision process by assisting the decision makers in resolving complex decisions and finding appropriate solutions.
Protocol data which are reported in a cross-national emergency exercise provide a basis for building a CBR system for decision support in crisis management, especially for a crises

involving large scale power blackouts. Since direct damages in critical infrastructures like power supply networks can lead to serious consequential problems in various sectors, a data structuring in order to identify affected domains and representative cases is necessary before building a case base (CL). A fundamental issue in building a case base is the appropriate selection and representation of cases in the CL. Therefore, adequate features (attributes which are measurable, differentiating and relevant) of the cases must be identified. Because of the high heterogeneity of the domains affected by a large scale power outage, further work needs to focus on the selection of relevant attributes. Thus, in order to develop an operationally applicable decision support system with integrated methods from CBR, further emergency exercises with an appropriate data documentation and expert interviews should be conducted in future. In this regard, experiences and results from the evaluation of LÜKEX 2004 can also be used in advance for an efficient planning of forthcoming large scale exercises in crisis management.

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