Decision support for managing interruptions in industrial supply chains

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1 Introduction: Critical Infrastructures

1.1 Disruption of critical infrastructures – the special role of power supply

Societies in developed countries depend heavily on the safe and secured operation of critical infrastructures such as energy, telecommunication, transportation, traffic and food and water supply, as well as social and medical care systems. Critical infrastructure (CI) can be severely damaged, destroyed or disrupted by technical failure (accidents), human failure (negligence), natural disasters, criminal activity or acts of terrorism which may lead to supply interruptions (EC, 2005). Interruptions within critical infrastructures may have a severe impact on industry and the economy, as well as the society as a whole. Due to an increased level of interdependencies between the various infrastructure sectors, the potential for cascading failure across mutually dependent systems is perhaps the most notable problem (Murray and Grubesic, 2007; UNISDR, 2002). Interruptions of infrastructure are often caused by extreme weather events like storms, snowfall, hail or periods of extreme temperatures. It is expected that due to climate change such extreme weather conditions will occur more frequently in the near future and thereby provoke an increased number of abnormal events within the sector of critical infrastructures (EEA, 2004). Affecting essentially all parts of society, economy or industry, energy supply is a very important part of critical infrastructure (Holmgren, 2007). An area-wide, secure electricity supply is essential for the functioning of a modern society (CEC, 2000). Thus, crisis situations in the energy sector constitute a special challenge. In Figure 1 potential cascading effects of a disruption of electricity supply are shown.

Figure 1: Potential cascading effects of supply disruptions in the electricity sector
Since most large-area blackouts are initiated by extreme weather events, also in the context of power supply security the consequences of climate change are of high importance (Ebeling and Böhmer, 2005). For example in 2005 in the “Münsterland” in the North-West of Germany the power supply was interrupted for up to four days due to extreme snow loads and the icing of power grids, while in the summer of the same year in Moskau and Greece the electricity supply collapsed because of unusually high temperatures.

In industrial infrastructures, supply interruptions (e.g. power blackouts) must be regarded with priority since negative effects and damage can propagate through the whole supply chain (Kleindorfer and Germaine, 2005). The fact that contemporary production systems have very complex structures and are globally interconnected increases the vulnerability of industry with respect to supply interruptions (Hendricks and Singhal, 2003; Papadakis and Ziemba, 2001). This makes a consistent and transparent risk management, especially in companies and producing facilities even more important.

1.2 Crisis management for critical infrastructures

Risk and vulnerability assessment as well as the analysis of the interdependencies between various critical infrastructures are the fundamental basis of an efficient infrastructure protection since in this allows to identify vulnerable elements of infrastructures and potential consequences of interruptions with the aim to guarantee secure supply. The vulnerability of critical infrastructures depends on various factors; besides technical elements, human and organisational elements, such as information systems or the organisation of failure management, play an important role and it is essential to identify critical infrastructure protection measures for each of these (Murray and Grubesic, 2007). Appropriate technical protection measures are e.g. the implementation of construction and building standards, the implementation of norms for retrofitting of critical infrastructure elements or the allocation of emergency equipments (e.g. emergency power generators). In order to minimise the risk of human failures it is important to create an appropriate risk awareness among the employees of critical infrastructure operators and within companies. Here, training for crisis management might be one solution. On the organisational level protection measures can be, for example, the preparation of emergency plans as well as a clear assignment of responsibilities.

In many industrial companies, “business continuity plans” or “business contingency plans” (BCPs) have been developed in recent years (Wieczorek et al., 2002). This practice is becoming more and more prevalent, due to a raise in awareness among corporate decision-makers about risk, increased regulatory pressure, consumer advocacy oversight, and public safety concerns. Additionally, there is more and more recognition that managing risk goes beyond organisational planning, and that risk management must become an integral part of the vision and mission of the company (Rössling, 2005). In Germany the aspect of the disruption of critical infrastructures was considered within the first cross national crisis management exercise, LÜKEX in 2004. A first systematic analysis of the results of this exercise and an approach for decision support will be described in the following paragraph.

2 Decision support for crisis management: Evaluation of the LÜKEX 2004 Exercise

2.1 Lükex 2004

The LÜKEX exercise was conducted by the Federal Office of Civil Protection and Disaster Assistance in four federal states of Germany. 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. Within the three day exercise, a scenario involving a large area blackout in the south of Germany due to thunderstorms and heavy snowfall was assumed. The main aim of this simulation exercise was to examine the reactivity to a trans-sectoral crisis in a large area.

2.2 Decision support for complex decision situations in crisis management

In case of a crisis situation like the one simulated in the exercise, decision making always has two goals. Firstly the safety of the staff and the population affected by the disaster has to be assured and secondly the continuation of or at least an early restoration of the critical infrastructure has to be achieved. Therefore, two complementary decision aiding approaches have to be adopted. In the early phase clear and distinct decisions have to be taken and appropriate alternatives of actions (potential
emergency strategies) have to be identified, whereas in the later phases of the emergency other factors such as political aspects and acceptance by the affected stakeholders become more relevant.

To learn from the LÜKEX exercise and from past power blackouts (e.g. blackout 2005 “Münsterland”), reported results and documented data can be analysed systematically with special focus on consequentially arising threats within various sectors (e.g. traffic, transportation water supply, communication). Based on these findings in the end a decision support for the crisis management in the event of large area blackouts could be developed. Therefore, in a first step, the consequences of direct damages to critical infrastructures within various sectors (transportation, traffic, communication technologies, administration, supply and waste management) must be analysed and the required emergency actions must be identified. Based on these results, a crisis management handbook for large-area power interruptions could be developed. Similarly to emergency handbooks for nuclear crisis, this handbook might contain checklists, decision trees, lists of emergency strategies and datasheets which describe the strategies in detail, for decision support (Brown et al., 2007). A second step could be the development of a more comprehensive decision support system (DSS).

2.3 Framework for the development of a decision support system

Since the resolution of complex decision situations in crisis and emergency management usually requires input from different disciplines and fields of expertise, often with conflicting interests, methods from the field of multi-criteria decision analysis (MCDA) can help to bring the various perspectives of the many stakeholder groups into some form of consensus and to ensure transparency of the decision making process (Geldermann et al., 2007; Hämiäläinen et al., 2000). Since the documented data of the LÜKEX exercise contain an enormous amount of information on consequences of large-area power blackouts and appropriate emergency measures’ it is obvious to use them as a foundation of a DSS. For the development of such a DSS we suggest to combine MCDA with case-based reasoning methods. One field of research within MCDA, which has proved to be suitable for application in the scope of emergency management (Geldermann et al., 2007; Hämiäläinen et al., 2000; French, 1996), is multi-attribute value theory (MAVT).

2.3.1 Multi attribute value theory

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. It facilitates decisions between different suggested alternatives (e.g. emergency strategies) and provides support for group decisions among various stakeholders affected by the crisis situation. 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. It is concerned with appropriately formulating rather than solving a problem and it is the first step for an identification of potential alternatives of actions (Belton and Stewart, 2002). However, in large-scale emergencies, problem structuring can become a very challenging task and standard problem structuring approaches might possibly fail.

2.3.2 Case-based reasoning and the combination with MAVT

In order to support and speed up the problem structuring process within MAVT, methods from case-based reasoning (CBR) can be used for a “preselection” of potential strategies. 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 (Kolodner, 1993). Since large scale exercises such as LÜKEX are conducted in order to be prepared for arising future crises, the documented results are implemented in a CBR-system and integrated in a DSS. The use of CBR in DSS may help the decision makers to structure the knowledge about potential emergency strategies. Thus, it acts to augment the decision makers memory about alternatives and helps to provide potential problem solutions (emergency strategies) for the person to consider that he or she might not be aware of (Kolodner, 1993). Figure 2 clarifies the combination of MAVT with CBR.
In CBR-Systems, previous cases are stored in a case library (CL). A case is typically a record comprising a problem description (state of the world when the case occurred, e.g. emergency situations) and the description of the corresponding solution (e.g. an emergency strategy) (Watson, 1997). The classical CBR process consists of four steps: the retrieve, reuse, revise and retain step (Aamodt and Plaza, 1994). The most important one is the retrieval step. In this step, the most similar case or a set of similar cases to an actual problem are determined within the CL. The retrieval is based on a measure of similarity between the current situation and the stored case. 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 (Watson, 1997). A fundamental issue in building an efficient CBR-System is choosing the 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). Since in case of an area-wide power interruption many different sectors are affected and many different crisis situations occur, it is impossible to find a case representation with uniform attributes which is appropriate for all cases within the LÜKEX data. Therefore, we suggest to create different case libraries, one for each affected sector, and to link them in the DSS.

One major advantage of CBR systems is the fact that they allow the decision maker to find potential solutions very quickly, reducing 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 addition, 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). 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 (Bertsch et al., 2006) and that MCDA as well as CBR necessitate input by the persons in charge and thus actively strive to involve them in the decision making process.

### 3 Conclusion

For the functioning of modern societies, a safe and secured operation of critical infrastructures is essential. However, critical infrastructure is characterised by a high vulnerability. Due to the frequent occurrence of extreme events in connection with climate changes and the increasing interdependencies between critical infrastructures, the risk of supply interruptions will be further increased. Especially in complex industrial supply chains, supply interruptions may be propagated via cascading failures. Crisis situations concerning critical infrastructure require fast reactions and the solution of complex decisions in order to minimise the risk for the population affected by the disaster and to assure the continuation of or at least the early restoration of the critical infrastructure.

For the facilitation of the decision process in crisis management various methods from the field of decision support are suitable. One simple possibility is the elaboration of handbooks with checklists, decision trees and lists of emergency measures for crisis management. A more comprehensive alternative would be the development of a DSS using methods from the field of MCDA and CBR as described on basis of the results of the LÜKEX 2004 exercise.

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**Figure 2: Combination of CBR and MCDA methods in a decision support system**

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Literature


