Multi Criteria Decision Support for Business Continuity Planning in the Event of Critical Infrastructure Disruptions

1. Introduction

Natural and man-made hazards such as floods, earthquakes, storms, terrorist attacks or industrial incidents do not only affect people and the environment, but also industrial companies, critical infrastructures and the economy as a whole can be severely affected. Prevalently, damages caused by natural disasters in the industrial sector are not restricted to directly hidden companies since the economic impacts can be propagated even into far off companies due to the complex interlacement within supply chains. Various events in the recent past such as for example Hurricane Katrina have shown that natural disasters and critical infrastructure disruptions constitute an important category of supply chain risks (Zsidisin, 2003).

From an economic point of view, modern industries can be affected by natural disasters in two different ways. First, direct losses due to physical damage to buildings and industrial installations (machinery, control installations, piping) the so called primary losses have to be considered (so called primary losses). Especially in the producing sector considerable losses caused by secondary hazards (e.g. release of hazardous materials in the chemical industry) and expenses for emergency, recovery and remediation measures might arise (so called secondary losses). (Cruz and Okada, 2008a). Besides these direct losses, industry may be seriously affected by indirect losses (Geldermann et al., 2008b). The amount of indirect losses might exceed the amount of direct losses multiple times (Kleindorfer and Germaine, 2005; Mechler, 2003). Indirect losses include all losses that are not directly caused by the damaging effect of the extreme event and occur – in time or space – outside the actual event. In general, these losses emerge from damages initiated by disruption of physical and economic linkages, e.g. losses due to the interruption of production (Messner et al., 2007). The direct reasons for the interruption of the production in the event of natural disasters can be manifold. Production downtimes can either be caused by direct damages within the affected company, by drop-out of a supplier company or by the disruption of critical infrastructures. Figure 1 gives a systematic overview of the potential losses of natural disasters in the industrial sector.

Since producing companies from all over the world are interconnected via complex supply networks, negative effects of natural hazards can be propagated via cascading effects and cause considerable physical and economic damages, even in regions and sectors not directly hidden by the negative event. Hence, an effective risk assessment and a structured and
effective industrial crisis management becomes more and more important in order to minimise economic losses and the propagation of damages triggered by natural disasters.

The main objective of this paper is to present a structured method for crisis management which enables the fast business recovery/business continuity within industries affected by natural disasters, in order to minimise follow-up costs of supply chain disruptions and to prevent the propagation of negative consequences within globally interlaced supply networks. After a description of general aspects of supply chain risks and the importance of critical infrastructures, the impacts of natural hazards and critical infrastructure disruptions to industrial production sites are described. In the next part we focus on selected topics of crisis management for supply chain disruptions, e.g. business recovery and business continuity planning. After the description of a quantitative method for business continuity planning from the field of multi criteria decision support, a case study is presented in the last part of this paper.

**Figure1**

2. Supply Chain Risks in Global Supply Chains

Modern production systems are organised as complex and highly interconnected supply networks. Within these networks industrial companies are exposed to different risks. So called supply chain risks are in general defined as the probability of an incident associated with the interrupted flow of goods and materials due to supplier failures, market fluctuation or extreme external events. The incidents often result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety (Craighead et al., 2007; Zsidisin, 2003). Supply chain risks can be classified according to the position of the risk source in relation to the considered supply chain into endogenous and exogenous risks (Pfohl, 2002). While endogenous risks are directly determined by characteristics of the supply networks and the single company, exogenous risks affect the supply chain from the environment. Endogenous risks comprise supply risks (e.g. drop-out of suppliers) as well as demand risks (demand fluctuations which may lead to “bullwhip effects” (Kersten and Hohrath, 2007; Lee et al., 1997)). Risks originating from outside of the supply chain are for example strikes, sabotage, terrorist attacks, natural hazards and disruptions of infrastructures which peril the continuity of production processes within the supply chain (Christopher and Peck, 2004). In the following we mainly focus on supply disruptions caused by natural disasters and infrastructure disruptions.
Due to the complex structure and the high degree of interdependency of modern supply chains, negative consequences of natural disasters and the associated supply disruptions are rarely limited to single companies and the economic impacts can be propagated via cascading effects very quickly and into far-off supply chain links.

2.1. Supply Chain Disruptions Caused by Natural Disasters and Critical Infrastructure Disruptions

Disruption risks within supply chains due to external events have received increasing attention in the last few years since, in the recent past, natural hazards and infrastructure disruptions caused several long-lasting disruptions in global supply chains leading to substantial economic losses (Kleindorfer and Germaine, 2005). For example the Taiwan earthquake 1999 affected the global semiconductor market and another earthquake which happened in the same year in Turkey, the Kocaeli Earthquake, led to serious breakdowns in the automotive supplier market and the chemical industry (Sezen and Whittaker, 2004; Papadakis and Ziemba, 2001). Furthermore the large power blackouts in the north-eastern U.S.A. and in Italy in 2003, as well as Hurricane Katrina in 2005, with economic losses of more than 80 billion US$, remind us that natural disasters and critical infrastructure interruptions can lead to long-lasting and cost intensive disruptions in supply chain activities (Wagner and Bode, 2006; Kleindorfer and Germaine, 2005; Christopher and Peck, 2004).

In general, risk assessment aspects within the supply chain management context are expected to become more important in the future because supply chain disruptions caused by external events are likely to occur more frequently due to several reasons.

One is that the vulnerability of companies and supply chains to disturbances and disruptions has increased considerably in the last years (Wagner and Bode, 2006; Christopher and Peck, 2004). The decrease of supply chain robustness is caused by a combination of various factors. For example, the increasing globalisation, the propagation of “just in time” production, the reduction of inventories as bound capital and the streamlining of production systems result in more and more complex and fragile supply chains (Peck, 2005).

Another reason responsible for a potential increase in negative supply chain events is the fact that natural hazards, like storms and floods are expected to occur more frequently in the near future due to climate change (EEA, 2004).

Supply chain disruptions triggered by extreme natural events often originate from direct damages to production sites of supplier companies. However, recent events showed that the impacts of natural disasters and the associated supply chain disruptions are often greatly
prolonged and exacerbated by interruptions of critical infrastructure systems (cf. Figure 1) (Chang et al., 2007).

2.2. Critical Infrastructures

Within modern societies especially the industrial sector depends heavily on the safe and secured operation of critical infrastructures (Merz et al., 2007). In literature critical infrastructures are defined as

“systems and networks comprising industries, institutions and distribution capabilities providing services which, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic well-being of a country or the effective functioning of its government” (GAO-01-32, 2001).

Usually the following eight infrastructure categories are defined as critical (GAO-01-32, 2001):

- Electricity Supply
- Transport
- Communication
- Water Supply
- Banking and Finance
- Chemical/Primary Industry
- Emergency Services
- Administration

Due to the complex network structure of critical infrastructure (CI), these systems 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 (Gheorghe and Vamanu, 2004; Mili et al., 2004). 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 prevention and protection measures for each of these factors (Murray and Grubesic, 2007; Luijif and Klaver, 2006). 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) (Little, 2003). 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.

Disruptions of 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; Robert, 2004; Rinaldi et al., 2001). The interdependencies within the different categories of critical infrastructures are presented in Figure 3.

Figure 3
Here, the exceptional position of the critical infrastructure of electric power production and transmission systems becomes evident. Affecting essentially all parts of society, economy or industry, electricity supply is a very important part of critical infrastructure (Zhang et al., 2008; Holmgren, 2007). An area-wide, secure electricity supply is essential for the functioning of a modern society, especially for the continuity of business and production processes (Mili et al., 2004; de Nooij et al., 2003). Thus, crisis situations in the electricity sector constitute a particular challenge. The case study which is presented in the last part of this paper focuses on power supply interruptions, the analysis of potential consequences to interlaced production systems and the development of an appropriate crisis management approach.

3. Impacts of Natural Hazards and Critical Infrastructure Disruptions on Industrial Supply Chains

For the development of an adequate crisis management programme which contains well structured emergency and business continuity plans for the industrial sector, knowing the potential effects and consequences of natural disasters and critical infrastructure disruptions is essential. In this context it is important to analyse the possible impacts on single companies/production sites as well as the effects to complex supply networks. Furthermore the impact assessment step allows the identification of extremely vulnerable objects and critical production processes, for which sophisticated crisis management measures are particularly important.

In general modern production systems can be affected by natural and man made hazards in different ways. Besides direct losses, including losses due to secondary hazards, indirect losses and losses caused by the interruption of critical infrastructures play an important role.

3.1 Impacts of Natural Hazards on Industrial Production Sites and Supply Chains

In industrial production sites direct losses are mainly caused by the partial or total damage of buildings, production equipment and piping as well as service and control installations (Geldermann et al., 2008b). The damage to industrial assets depends on the magnitude of the hazardous event (in time, space and type), the vulnerability of the assets and the exposure of
the elements at risk (Crichton, 1999). Therefore the extent of the direct losses cannot be anticipated overall, but must be assessed quantitatively and separately in detail for each industrial sector according to different hazard scenarios (for detailed assessment methods see (Geldermann et al., 2008b; Schneider and Schauer, 2006; Penning-Rowsell et al., 2005). 

In addition to physical damages and economic losses in some industrial sectors, natural hazards like storms, earthquakes and floods can induce secondary hazards (Cruz and Okada, 2008b). Here the chemical industry takes an exceptional position since natural disasters can cause the release of hazardous substances which may result in severe environmental pollution, explosions, fires and the threat to staff. These so called natural hazard-triggered technological disasters (Natechs) are relatively rare, but the social as well as the environmental consequences of such events can be devastating (Cruz and Okada, 2008b). This becomes apparent in some recent Natech events. For example the Kocaeli Earthquake 1999 resulted in the release of various hazardous chemicals (Sezenia and Whittaker, 2004) and in August 2002 as a result of severe floods in the Czech Republic huge amounts of chlorine were released into the river Labe (Cruz and Okada, 2008a).

Direct damage to industries as well as secondary disasters-triggered secondary disasters may lead to indirect damages within single companies, entire supply chains and the environment. Due to production downtimes usually caused by the physical damage of the production equipment and important infrastructures, severe economic losses might occur. These losses in some sectors can be in the order of three to ten times larger than direct losses (Kleindorfer and Germaine, 2005). Additionally, the production downtimes are not restricted to directly affected companies, since modern production systems are interlaced networks where negative effects can be propagated via cascading effects into far-off links of the supply chain. Thus, companies in other regions and from different industrial sectors can be affected by one single hazard-event, and natural disasters rank among the most important categories of supply chain risks (cf. 2.1).

### 3.2. Impacts and Consequences of Critical Infrastructure Disruptions in Supply Chains

The above described consequences of natural disasters might be prolonged and strengthened by the simultaneous interruption of critical infrastructures, which are of great importance for the continuity of production processes but due to their complex network structure very vulnerable to natural disaster-triggered interruptions themselves (Perrow, 1999). In the following part of the paper and in the case study described below, we focus on the
interruption of the electricity supply because this is the most critical infrastructure for the sector of industrial production.

In the first instance power blackouts are responsible for production downtimes, which may lead, as described above, to severe economic losses within single companies and entire supply chains (via cascading effects). Furthermore by sudden voltage decrease sensitive manufacturing facilities might be damaged and raw materials, finished products and products in stock might become inoperative, especially if they need cooling or any other special electricity demanding treatment during storage.

In some industrial sectors power supply interruptions may cause secondary hazards. Some recent events showed that for example in the chemical industry accidents were triggered by electrical power outages (e.g. NOVA chemicals Pittsburgh, April 2005) (NRC, 2008). In case of a blackout, n the chemical industry, the breakdown of measure and control installations as well as the interruption of cooling and mixing equipments may lead – if no countermeasures are taken – to accidental events and the release of hazardous material into the production environment (EPA, 2001). Furthermore it is possible that through the malfunction of valves and pumps gas leakages and subsequent explosions might occur.

But not only the sudden breakdown of power supply constitutes a problem in the chemical industry, also the abrupt return of electricity might be dangerous(EPA, 2001). For example in 2001 the unsafe shutdown of a sulphuric acid production and the sudden restart of production processes when the electricity returned, resulted in the release of large volumes of sulphur dioxide (SO\textsubscript{2}) and sulfur trioxide (SO\textsubscript{3}) to the environment (EPA, 2001).

The described risks and impacts of natural disasters within supply chains and in single companies might be mitigated and prevented. For the reduction of direct damages technical protection measures (e.g. dikes, drip pans, early warning equipment) are useful and responsible planning decisions should be made (reasonable site selection, risk awareness during the planning phase). In order to prevent supply disruptions and production downtimes in not directly hidden companies robust supply chains with alternative suppliers and redundant inventories should be considered (Christopher and Peck, 2004). Although these prevention measures are very useful and should be realised in order to reduce the risk as far as reasonable, not each damage and each accident can be prevented since (according to Perrow’s Normal Accident Theory) in complex and tightly coupled networks accidents become quasi inevitable (Perrow, 1999).
4 Crisis Management for Supply Chain Disruptions

Since the risk of negative external events (e.g. natural disasters and critical infrastructure disruptions) and subsequent disruptions of the supply chain cannot be completely avoided it is important for industrial companies to have a well structured and sophisticated crisis management strategy which increases the companies’ abilities to cope with potential threats and consequences of natural disasters (Smith, 2006). The main objective of industrial crisis management strategies is the reduction of the negative consequences of natural disasters and critical infrastructure disruptions, the avoidance of secondary hazards as well as a fast business recovery and the retention of the continuity of important production processes. Therefore, clearly elaborated crisis management programmes can help to reduce the potential impacts (physical and economic) of natural disasters and supply chain disruptions to a reasonable minimum and to avoid environmental and human damages.

In recent years, many industrial companies implemented “business continuity plans” (BCPs) in order to cope with the consequences of supply chain disruptions and impacts of natural disasters (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 (Wieczorek et al., 2002).

BCP can be defined as a framework that helps companies to recover from a disaster that has caused a disruption of business operations by the integration of formalised procedures and resource information (Barnes, 2001). The BCP process is aimed at an enhanced creation of risk awareness, the identification of potential prevention possibilities but mainly at the development of structured contingency and recovery plans in order to increase the overall coping capacity of companies in the event of a disaster, to reduce production downtimes and to enhance the robustness of interlaced modern supply chains (Zsidisin et al., 2005). Initially, the focus of BCP has been on information technology (Savage, 2002). However, recent events (e.g. the terror attacks of 11 September 2001 and the power disruptions in 2003 in Europe and the U.S.A.) showed that business continuity aspects are important for almost all industrial sectors everywhere.

Formally, a BCP process consists of four or more consecutive components. While some authors tend to suggest a more detailed subdivision of the BCP process (Chapman et al., 2002; Gilbert and Gips, 2000) we prefer a four-part framework with the following components:
- Impact assessment
- Risk analysis
- Plan development
- Plan audit and training

Within the first phase of (“impact assessment”) of the BCP-process, potential consequences of natural disasters and supply chain disruptions for the business processes are analysed and particularly vulnerable and critical production processes and installations are identified. In the second step the probability of occurrence of natural hazards and supply or infrastructure disruptions are assessed. While for the risk analysis step various quantitative and qualitative assessment methods can be found, for the step of impact assessment mainly qualitative descriptive approaches (e.g. workshops, scenario-based interviews) are used (see section 3 and 6) (Zsidisin et al., 2005).

Based on the findings of phase one and two, the proper business continuity plans are developed in the third step, the main phase of BCP of the framework. These plans cover:
- Emergency response plans (procedures, measures, reporting)
- Business recovery plans (technical aspects)
- Communication plans (offices stakeholder etc.)
- Resource planning (e.g. material, workforce, finance)
- Determination of responsibilities (e.g. lists containing contact persons, addresses, etc.).

The main task of the development step of a BCP is the structured identification and evaluation of emergency and recovery measures, the determination of responsible people and communication strategies as well as a proper planning of resources, needed for the restoration of normal production and business processes (Johnson McManus and Carr, 2001).

Only a few approaches from practitioners can be found in literature (similar to step two) which are in most cases qualitative and descriptive methods for the phase of plan development (Zsidisin et al., 2005). However, especially the development of adequate and well structured emergency and recovery plans might be a challenging task, because the decision situations in crises are often very complex and potential actions (suitable emergency and recovery measures) are difficult to identify (Geldermann et al., 2008a). After the identification of potential measures for emergency plans, the various alternatives must be evaluated and the most suitable actions must be defined. This often requires the consideration of various criteria (economic, ecologic, social, etc.) and the trade-off between conflicting objectives (Bertsch, 2008). Furthermore different stakeholder and expert groups are involved in the planning process and contradictory opinions must be integrated in the decision making
process. Hence, environmental, personnel related, organisational and legal as well as health and safety aspects must be regarded within the BCP process for industrial crisis management. In order to give consideration to the described requirements, methods from the field of multi criteria decision analysis can be helpful for emergency and continuity planning within industrial crisis management. The application of multi criteria decision support methods for BCP is described in the following section.

5 Structured Decision Support for BCP

Decisions in the context of crisis management planning involve many parties who usually have different views, responsibilities and interests (Geldermann et al., 2008a). 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 – in a consistent manner – knowledge from diverse disciplines. Furthermore, MCDA methods can help to consider various incommensurable levels of information and to consider the subjective preferences of the responsible decision makers in the process of crisis management planning (Bertsch et al., 2007).

Various MCDA techniques, based on different theoretical foundations have been developed (e.g. multi-attribute value theory (MAVT), multi-attribute utility theory (MAUT), outranking approaches (e.g. PROMETHEE)). However, they all have in common that they tend to facilitate the analysis of multiple streams of unalike information in a structured way and that they can help to reduce the incomparability between various alternatives by explicitly incorporating preferential information of the decision makers (Linkov et al., 2004).

One field of research within MCDA, which has proved to be suitable for application in the scope of emergency and crisis management (Geldermann et al., 2008a; 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 the elicitation of the relative importance of different criteria in such a tree. Thus, it enables the evaluation and comparison of different alternatives (e.g. in BCP different emergency or continuity measures) with respect to different criteria (e.g. economic, ecological, social, legal aspects). The essential interactive steps in a MAVT analysis (Figure 4) are problem structuring, preference elicitation, aggregation, sensitivity analysis and finally a ranking of the decision alternatives (Belton and Stewart, 2002).

Figure 4
5.1 Problem Structuring

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. For the identification and specification of objectives (criteria) and attributes as well as the determination of potential decision alternatives (e.g. potential emergency or continuity measures within BCP) in the problem structuring step hierarchical attribute trees are developed. In an attribute tree the overall goal (objective) of the decision situation is divided hierarchically into lower level objectives (criteria) and – on the lowest – level measurable attributes.

5.2 Preference elicitation

After structuring an MCDA problem into a hierarchical attribute tree, the preferences and value judgements of the decision makers need to be evaluated with respect to the different criteria. Therefore, the performance scores (value) of each alternative, according to each measurable attribute value and the relative importance amongst the different criteria have to be modelled (Belton and Stewart, 2002).

For the determination of the performance score of an alternative, value functions are defined which map the measurable values of an attribute on a scale between 0 and 1, such that “best” and “worst” possible outcomes correspond to 1 and 0 respectively:

\[ v_i : \mathbb{R} \rightarrow [0,1] \]

\[ s_i(a) \mapsto v_i(s_i(a)). \] (1)

with

- \( a = \) decision alternative
- \( v_i = \) value of alternative \( a \) with respect to attribute \( i \)
- \( s_i(a) = \) the score of alternative \( a \) with respect to attribute \( i \) \((1 \leq i \leq m, m = \) number of attributes).

Concerning the comparison of the relative importance amongst the criteria, weights can be determined by different weighting procedures. The simplest way is to give them directly by point allocation (DIRECT weighting). Other very common weighting methods are the SWING procedure or the SMART method. For comparison and details of the use of the different methods see (Bertsch et al., 2006; Belton and Stewart, 2002).

5.3 Aggregation
After the determination of a value of an alternative according to each single criterion and the determination of weights the overall values of the different potential alternatives are determined. Assuming mutually independent attributes, the standard additive aggregation rule can be used and the overall value of an alternative $a$ can be calculated as (Keeney and Raiffa, 1976)

$$V(a) = \sum_{i=1}^{m} w_i v_i(s_i(a))$$

(2)

where $w_i$ is the weight (relative importance) assigned to attribute $i$ with $\sum_{i=1}^{m} w_i = 1$.

Based on these overall values the potential alternatives can be ranked against each other and the most suited alternative can be identified.

5.4 Sensitivity analysis

In the last step of the MAVT procedure, the robustness of a decision can be analysed in a sensitivity analysis. Here, the effects of weight variations and the modification of value functions can be examined. This step becomes especially important since each decision analysis is to a certain extent influenced by subjectivity (elicitation of weights, determination of value functions). The sensitivity analysis for the attribute “costs” is shown in Section 6.

Various user-friendly software tools (e.g. the “Simulation-Based Multi-Attribute Decision Analysis” (SIMADA), Web-HIPRE) may support the above described phases of a MAVT analysis (Bertsch and Geldermann, 2008; Mustajoki and Hämäläinen, 2000). The application of the MAVT in the field of BCP in the event of natural disasters and critical infrastructure disruptions as well as exemplar results generated with SIMADA are presented in the following section.

6 Case study

In the following the above described methods are exemplarily applied to a case study. Base of this case study is the evaluation of the first cross national crisis management exercise “LÜKEX 04” conducted in 2004 and the analysis of real blackouts (e.g. 2005 in the “Münsterland” area; 2003 in Italy).

The first national crisis management exercise after the cold war in Germany, LÜKEX, was conducted by the Federal Office of Civil Protection and Disaster Assistance (BBK) in four Federal States of Germany in 2004. During this exercise, 6000 participants from administration, police and industry practiced how to deal with arising threats caused by a natural hazard-induced blackout 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, manufacturing companies 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 main aim of the study is the further evaluation of the documented LÜKEX-data in order to use them as a basis for the development of a practically oriented handbook for crisis management in the event of power disruptions to facilitate decisions and the overall disaster coping.

Therefore, in a first step in order to evaluate the impact and potential negative consequences of power disruption within various social and economic sectors, the LÜKEX-data and information on real power blackout have been analysed and particularly vulnerable sectors were identified. The results reveal that impacts caused by power supply interruptions are exceptionally severe in the sectors communication technologies, medical care, food and water supply and industrial production. Since this paper is mainly focused on impacts of natural disasters and critical infrastructure disruptions on industry, we only refer to the results for the industrial sector in the following. In order to reduce the impacts of power supply interruptions to supply chains as described in Section 3 the implementation of a well structured and easily applicable industrial crisis management strategy is necessary. As elaborated in the previous section the development of a BCP in the forefront of disasters plays an important role. Within the presented case study, for the identification of potential emergency and continuity measures scenario-based, moderated workshops with experts from the affected industrial sectors are hold. Here, special focus will be again on the sector of chemical industries, since the chemical production processes are especially endangered and pose a secondary hazard to people and the environment.

For the development of exemplary BCPs the potential measures (alternatives) identified in the workshops must be evaluated and compared to each other. This evaluation of emergency and continuity measures requires the integration of various different and often conflicting criteria. Besides economic characteristics, ecological and social as well as health and safety aspects play an important role concerning the applicability of a potential measure. Such complex decision situations within the BCP process can be solved by the application of MCDA methods, e.g. a MAVT analysis. The MAVT method is supported by various user-friendly
decision support tools (e.g. SIMADA) which support the problem structuring process as well as the elicitation of preferences and the evaluation of overall values of different alternatives (Bertsch and Geldermann, 2008). In the following we present the results elaborated with SIMADA for a decision analysis for the evaluation of potential (hypothetical) alternative continuity measures in the chemical industry.

The four BCP-measures analysed for illustrative purposes are described in Table 1. Within the first step of the decision analysis the decision problem is analysed and a hierarchical attribute tree is developed (Figure 5).

### Table 1: Scheme of potential (hypothetical) BCP-measures for chemical production sites during blackouts

<table>
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<tr>
<th>Name</th>
<th>Characterisation</th>
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<tbody>
<tr>
<td>BCP 1</td>
<td>No Action: no special emergency and continuity measures are implemented</td>
</tr>
<tr>
<td>BCP 2</td>
<td>Safe shut down of processes, in order to prevent secondary disasters, no further emergency and continuity measures</td>
</tr>
<tr>
<td>BCP 3</td>
<td>Set up of continuity and emergency measures (e.g. the operation of emergency power supply and transfer to replacement facilities) in order to prevent environmental impacts and to maintain parts of the production processes.</td>
</tr>
<tr>
<td>BCP 4</td>
<td>Similar to BCP 3, combined with the elimination of interruption causes in order to secure an independent electricity supply and to enable the continuity of production processes</td>
</tr>
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The overall goal “adequate BCP-measure” is subdivided into three objectives: “acceptance”, “costs” and “effectiveness” of the BCP-measures. On the lowest hierarchical level those objectives are described by measurable attributes Figure 5, boxes light colored frames. In the described case the acceptance by workers and by the population, as well as costs and resources needed when implementing a BCP-measure are considered to be important. Furthermore, environmental impacts (measured as the amount of hazardous materials released (HAZMAT) and the toxicity) and production aspects (duration, of the BCP-measure, production downtimes and potential domino effects) play an important role.

**Figure 5**

The second step of the evaluation assesses the preference of the decision makers and aggregates the value of each alternative with regard to each criterion to an overall value of an alternative (cf. Section 5). The typical stacked-bar chart (Figure 6) depicts the overall values of the four compared alternatives. Furthermore the composition of the particular bar shows the contributions of each criteria. The ranking of the four alternatives points out, that for the
assumptions made in this analysis, alternative BCP 4 should be preferred to the other alternatives (BCP1, BCP 2, BCP 3) and that the criteria of “environmental impacts” and “production aspects” are most important for the decision.

Figure 6
Besides illustrating the overall performance scores of the considered alternatives, the robustness of the decision plays an important role (Bertsch et al., 2006). The graph of a sensitivity analysis (Figure 7) allows an examination of the stability of the decision result with respect to changes of the criterion under consideration.

Figure 7
The sensitivity analysis for the criterion “costs” reveal, that if the weight exceeds 70% the ranking changes and BCP 4 is exceeded first by BCP 2 and than by BCP 1. Sensitivity analyses can help to solve group decisions in a transparent way, this enables the facilitation of the decision situation and the faster development of a BCP, which involves stakeholders from very different fields.

7 Conclusion
Modern supply chains are exposed to various different categories of risks. Within globally interlaced supply networks, especially external risks like natural disasters play an important role and single companies as well as interlaced production systems can be severely harmed either by direct and indirect losses or secondary hazards (Cruz and Okada, 2008a; Geldermann et al., 2008b). Supply chain disruptions show a relatively low probability of occurrence, but the consequences can be severe and the diverse impacts might be propagated via so called cascading effects (Zsidisin, 2003).

In industry, the negative impacts of natural disasters can be prolonged and strengthened by the simultaneous interruptions of critical infrastructures, since their failure-free functioning is an important prerequisite for the continuity of complex and interconnected production processes (Zhang et al., 2008; de Nooij et al., 2003). Due to the complex network structure of critical infrastructures and the high degree of interdependencies within the different sectors of CI (e.g. electricity supply, water supply, transport, administration) they are very vulnerable themselves and interruptions might be propagated easily within the different CI sectors (Murray and Grubesic, 2007; Robert, 2004).

In order to minimise the follow-up costs and total monetary losses of supply chain disruptions triggered by natural disasters and the subsequent failure of CI an efficient and transparent
A crisis management strategy is needed within single companies as well as within the operators of critical infrastructures. Hence, for the reduction of production downtimes and a fast business recovery, many companies currently implement business continuity plans (BCP). Since BCP is an important topic in the practitioners world, mainly descriptive approaches for BCP-design are available. However, because of the complex nature of decision situations within crisis management planning, it would be desirable to have more sophisticated (quantitative) methods for the design of business continuity plans, in order to ensure a well structured and comprehensible development of BCPs within each level of the supply chain. As presented in this paper by means of a case study, methods from the field of MCDA (e.g. MAVT) can be helpful for emergency and continuity planning within industrial crisis management. These methods help to facilitate group decisions and enhance the overall comprehensiveness of complex decision situations which is one of the most important challenges within industrial crisis management.

Besides further elaboration and practical testing of the application of MCDA methods for industrial BCP development, future work should focus on the analysis of the propagation of negative disaster impacts within global supply chains, since the understanding of cascading effects is an important premise for the implementation of adequate crisis management and business recovery strategies.

References


FIGURES AND TABLES

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<th>Direct losses</th>
<th>Indirect losses</th>
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<tr>
<td>Primary losses</td>
<td>Loss of production</td>
</tr>
<tr>
<td>Buildings</td>
<td>... due to direct losses</td>
</tr>
<tr>
<td>Assets</td>
<td>... due to supply disruptions</td>
</tr>
<tr>
<td>Raw material</td>
<td>... due to critical infrastructure disruptions</td>
</tr>
<tr>
<td>Control</td>
<td></td>
</tr>
<tr>
<td>Piping</td>
<td></td>
</tr>
<tr>
<td>installations</td>
<td></td>
</tr>
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</tr>
</tbody>
</table>

![Table: Industrial Losses caused by Natural Disasters](image)

**Figure 1: Industrial disaster losses (adapted from (Green et al., 2000))**

![Diagram: Supply chain risks](image)

**Figure 2: Supply chain risks (adapted from (Kersten and Hohrath, 2007))**
Figure 3: Interdependencies among critical infrastructure systems (adapted from (Pederson et al., 2006))

Figure 4: Key phases of MAVT (adapted from (Belton and Stewart, 2002))

Figure 5: Hierarchical attribute tree for the evaluation of BCP-measures
Figure 6: Overall performance scores and contribution of criteria to overall performance scores, calculated with SIMADA

Figure 7: Sensitivity analysis for the criterion “costs”