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IV. ABBREVIATIONS

CDC…………………………...Centers for Disease Control and Prevention
CHF…………………………Swiss Franc
CRED………………………Centre for Research on the Epidemiology of Disasters
DES…………………………Discrete Event Simulation
DSS…………………………Decision Support System
GDP………………………...Gross Domestic Product
GIS…………………………Geographic Information System
e.g. ………………………… exempli gratia (for example)
EM-DAT……………………Emergency Events Database
ER…………………………..Emergency Room
hazmat………………………hazardous material
i.e. …………………………..id est (that is)
IT……………………………Information Technology
JCR…………………………Journal Citation Report
OR/MS……………………...Operational Research/Management Science
OR…………………………..Operational Research
PML………………………...Probable Maximum Loss
QALY………………………Quality-Adjusted Life Years
RS…………………………...Remote Sensing
SEC…………………………Strategy Effectiveness Chart
Swiss Re……………………Swiss Reinsurance Company
UN…………………………..United Nations
UN/ISDR……………………United Nations/International Strategy for Disaster Reduction
US…………………………...United States
USA…………………………...United States of America
USD………………………....United States Dollar
VaR…………………………Value at Risk
2D…………………………...2-dimensional
3D…………………………...3-dimensional

1 INTRODUCTION

As the occurrence of disasters is getting more and more frequent and the accumulated loss of these events is getting higher and higher, there is a strong need for the development and implication of strategies to counter these disasters. Almost each day, messages about earthquakes or other disasters are in the news, reminding us of the vulnerability of the mankind to such events. In November 2007, over 4,000 people were killed by cyclone Sidr in Bangladesh, the floods in China in June and July affected over 105 million people in 2007[1]. In total, disasters occurring in 2007 caused 16,748 casualties, affected 211 million people worldwide and resulted in more than USD 74.9 billion in economic damage[2].

A considerable amount of science directions has focused on the various aspects of disaster management and its impacts on mankind, flora and fauna, as well as the economy as a whole. The range of different aspects considered encompasses public choice approaches[3], psychological analysis of people affected by disastrous events to surveys on how disasters affected business[4] and how indigenous techniques might be useful in order to mitigate the effects of a disaster[5]. The importance of environmental planning in the Operational Research (OR) literature has increased during the last decades, as well as the focus on risk assessment and management[6]. Moreover, also the earth science perspective helps evaluate mitigation strategies due to the insertion of satellites and so on[7].

Each of the above mentioned approaches has its justification but this thesis focuses on the economic motivation of disaster management and disaster management related research and the models and methods used to evaluate different courses of action. In order to follow this approach, the scope of this thesis is to give an overview of the literature in the field of disaster management, especially in the field of OR. Disaster management in this context comprises the management of natural and technological disasters as well as the management of the different terrorism forms. It is not intended to give an exhaustive listing of all disaster-management related articles ever published, but to underline the current research directions and to show the economic evaluation of the measures taken.

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[1] Cp. [290] CRED (2008), p. 23f. [access on June 1st, 2008].
[2] Cp. [290] CRED (2008), p. 11. [access on June 1st, 2008].
[3] Cp. [255] Shughart II (2006), p. 31ff.
[4] Cp. [267] Tierney (1997), p. 87ff.
[5] Cp. [245] Rautela (2005), p. 233ff.
[6] Cp. [132] Daniel et al. (1997), p. 252f.
[7] Cp. [277] Williamson et al. (2002), p. 57ff.

In a first step, a general overview of the literature is given. In a second step, the taxonomy focuses on models and outcomes presented in the literature. As a result of the review of the literature, appropriate categories for the disaster management taxonomy are derived. On the one hand, an overview of general model features, i.e., the level of disaster management, model type and methods of application is given. On the other hand, the type of intervention used and the practicability for different disaster types are discussed.

The main focus of the taxonomy lies on the economic analysis, which encompasses effectiveness-related, resource-related, and cost-related parameters and shows the type of economic analysis used in the literature. We analyze whether economic analysis, i.e., cost-utility, cost-effectiveness, and cost-benefit are used to investigate different interventions and what type of analysis has been chosen by the authors.

Policy implications and results show that considerable improvements can be achieved for different disastrous events and in different situations.

Although global climate warming is the catalyst of disastrous natural events, further investigation of this phenomenon will not be included in the thesis, however it has to be kept in mind that this is the main reason for the increase of the amount of disasters occurring during the last decades[8].

[8] Cp. [290] CRED (2008), p. 14. [access on June 1st, 2008].

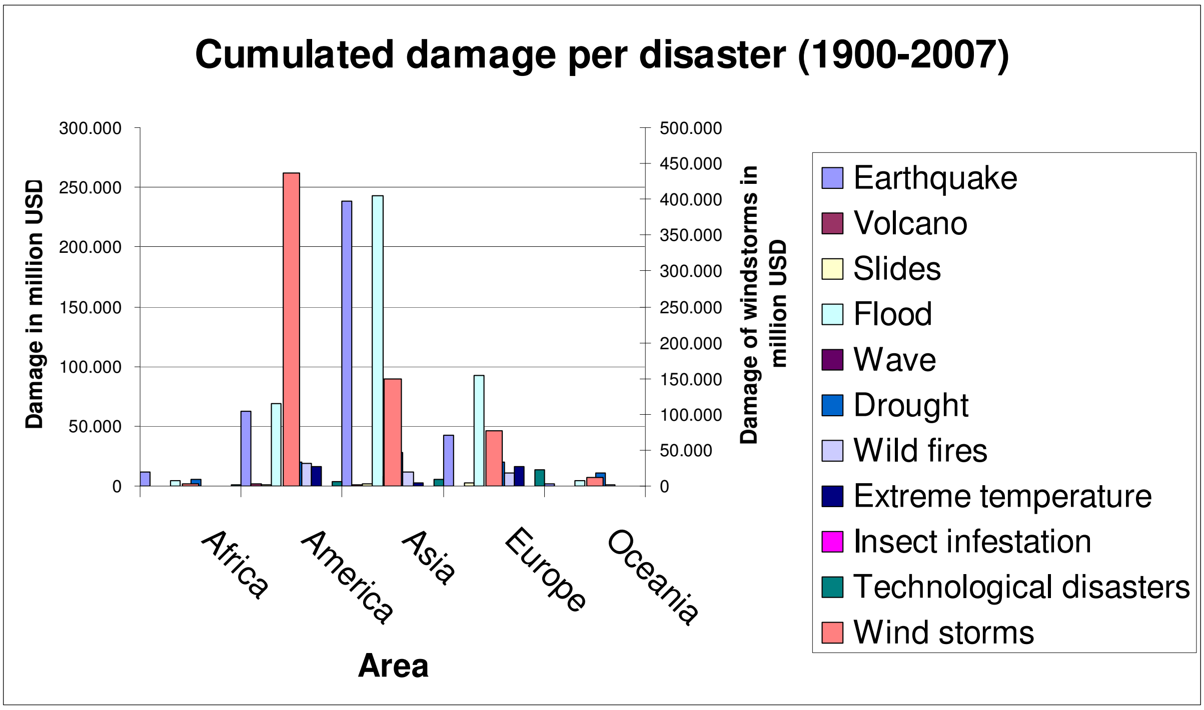
2 ECONOMIC EVALUATION OF DISASTERS

2.1 Impact of Disasters Worldwide

The number as well as societal and economic impacts of disasters all over the world are increasing. Therefore it gets more and more important to prepare for such incidences and to further increase the awareness of people worldwide. As the figures of the Emergency Events Database (EM-DAT) [9] of the Centre for Research on the Epidemiology of Disasters (CRED) show, there is a strong need for further emphasis on this topic in order to prevent a massive loss of human lives and further economic loss. With regard to natural and technological disasters, the following picture arises.

As can be seen in Figure 1, Asia, as being the most populated continent in the world, is also the one mostly affected by natural disasters as for example earthquakes and flooding, leaving damage caused by wind storms aside. Recent disasters like the earthquake in Sezchuan in May 2008 or the tsunami of December 2004 caused thousands of deaths and affected economic structures strongly.

Figure 1: Cumulated damage per disaster per geographic region



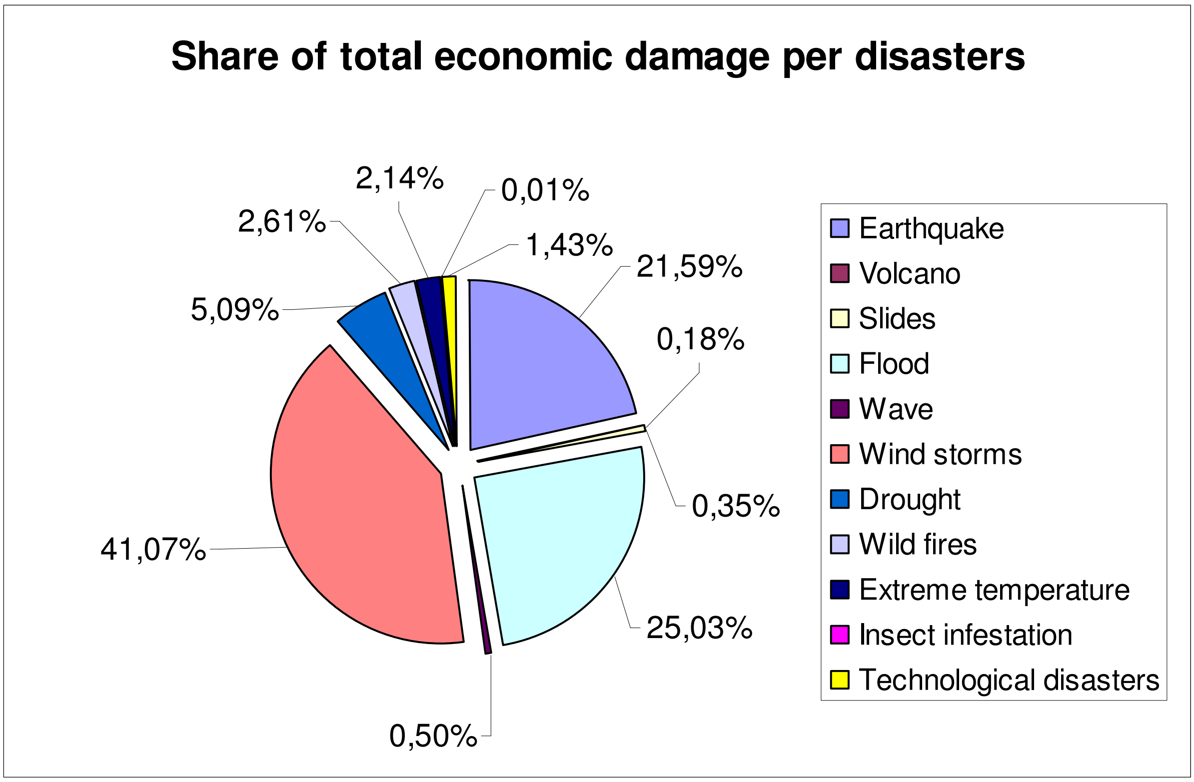
Source: Own illustration, based on data of the EM-DAT[10]

[9] Cp. [291] EM-DAT [access on June 5th, 2008].
[10] Cp. Ibidem.

The most conspicuous result, however, is that wind storms caused the highest cumulated economic damage worldwide, with Hurricane Katrina being one of the most expensive natural damages ever occurred. Compared to natural disasters, technological disasters have a very small share in terms of overall damage, still they caused considerable damage in Europe.

Figure 2 shows that of all economic damages caused by natural disasters, 41% of the damages are caused by wind storms, 25% by floods, and 22% by waves. The remaining 12% of economic damage either result from drought, wild fires or extreme temperatures, technological disasters only account for 1% of total damage.

Figure 2: Share of total economic damage per disaster type



Source: Own illustration based on data of the EM-DAT[11]

A list of the ten most harmful disasters in terms of cumulated economic damage that have occurred during the last three decades can be found in Table 1.

Hurricane Katrina, as already mentioned above, has been the most damaging natural disaster with an economic damage of USD 125 billion. In the Top 10 list of disasters in terms of economic loss, five disasters were caused by wind storms and six out of ten disasters occurred in the United States of America (USA).

[11] Cp. [291] EM-DAT [access on June 5th, 2008].

Considering only insured losses and including all different disaster types the picture slightly changes. Hurricane Katrina remains the most costly disaster, but as can be seen in Table 2, the terrorist attack of the World Trade Centre in New York is the third costly disaster ever occurred in terms of insured losses. Another remarkable fact is that nine of the ten disasters mentioned in the table hit the USA.

Table 1: List of the ten most costly natural disasters in terms of overall economic damage

Country	Date	Name of disaster	Economic Damage (in million USD)
USA	29.08.2005	Hurricane Katrina	125,000
Japan	17.01.1995	Great Hanshin earthquake (Kobe)	100,000
China	01.07.1998	China flood	30,000
USA	17.01.1994	Northridge earthquake	30,000
Japan	23.10.2004	Nigata earthquake	28,000
USA	23.08.1992	Hurricane Andrew	26,500
Italy	23.11.1980	Irpinia earthquake	20,000
USA	15.09.2004	Hurricane Jeanne	18,000
USA	11.08.2004	Hurricane Charley	16,000
USA	20.09.2005	Hurricane Rita	16,000

Source: Own illustration based on data of the EM-DAT[12]

One of the reasons why the two tables differ from each other might be that in the developed country, USA, property is overall better insured compared to property in less developed countries. Therefore, the earthquakes and floods mentioned in the first table do not appear in the second table. Nevertheless the losses caused by disasters are considerable independent on the variables taken into consideration in the evaluation.

Table 2: List of the ten most costly disasters in terms of insured losses

Country	Date	Name of disaster	Insured Losses (in million USD)
USA	25.08.2005	Hurricane Katrina	66,311
USA	23.08.1992	Hurricane Andrew	22,987
USA	11.09.2001	Terror attack WTC	21,379
USA	17.01.1994	Northridge earthquake	19,040
USA	02.09.2004	Hurricane Ivan	13,651
USA	19.10.2005	Hurricane Wilma	12,953
USA	20.09.2005	Hurricane Rita	10,382
USA	11.08.2004	Hurricane Charley	8,590
Japan	27.09.1991	Typhoon Mireille	8,357
USA	15.09.1989	Hurricane Hugo	7,434

Source Own illustration based on data of Swiss Re[13]

[12] Cp. [291] EM-DAT [access on June 5th, 2008].
[13] Cp. [293] Swiss Reinsurance Company, Sigma No2/2007, p. 35ff. [access on April 5th, 2008].

An effective framework of economic analysis is therefore crucial in order to save lives and reduce property damage as well as to decide upon the most efficient strategies to guarantee an optimal allocation of scarce resources throughout the disaster management process.

2.2 Economic Analysis in Disaster Management

"[…] economic analysis can contribute by providing information for the political choice of a standard of protection against natural hazards and on how to achieve the politically determined standard"[14]. Cost-benefit analyses are widely used to investigate economic costs and benefits in the decision making process[15], all costs and benefits are valued in monetary terms[16]. These analyses further allow "to evaluate the net worth of a project and can then be used to compare projects, even those of different qualifications"[17] and are therefore "a tool for intersectoral resource allocation"[18].

Cost-effectiveness analyses do not value health in monetary terms but in other units such as life years gained. They allow to directly compare projects with similar objectives[19].

One major difficulty in the economic analysis of disaster management is the fact that various protection measures, as for example avalanche protection measures, are considered to be local public goods. The marginal cost for one additional beneficiary is equal to zero, therefore a regulation via market prices leads to an undersupply of this public good. The second feature of the public good, non-excludability, leads to the well-known free-rider problem, as people can procure the benefit of the public good without contributing for its supply i.e., paying for the supply[20].

Furthermore, the evaluation of non-monetary values in a cost-benefit analysis as for example human life with the human capital approach causes problems, as ethical concerns arise due to the fact that older people are valued less than younger people in this approach[21] or different

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[14] [37] Fuchs and McAlpin (2005), p. 328.
[15] Cp. [37] Fuchs and McAlpin (2005), p. 328.
[16] Cp. [187] Heidenberger (1996), p. 3.
[17] [187] Heidenberger (1996), p. 3.
[18] [187] Heidenberger (1996), p.3.
[19] Cp. [187] Heidenberger (1996), p. 3.
[20] Cp. [37] Fuchs and McAlpin (2005), p. 328.
[21] Cp. Ibidem.

reference values are used[22]. The willingness-to-pay approach is broader accepted, as it focuses on the amount of money each individual is willing to spend for different improvements[23]. A real options approach has shown that in certain cases even when the normal cost-benefit analysis would not consider an alternative as being effective, it might though be an optimal public investment from an economical point of view[24].

The effects of large scale extreme events on the Gross Domestic Product (GDP) can be assessed by a non-equilibrium dynamic model. It has been found that if the severity and frequency of disasters remain under a certain threshold level, the losses in GDP remain moderate[25].

Strategic economic risk management preparedness planning including the evaluation of direct and indirect economic costs is crucial for effective disaster management. Input-output analysis and system econometrics are the most commonly used economic analyses of hazardous events[26].

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[22] Cp. [50] Kappos and Dimitrakopoulos (2008), p. 53.
[23] Cp. [187] Heidenberger (1996), p. 3.
[24] Cp. [152] Farrow and Hayakawa (2002), p. 167.
[25] Cp. [181] Hallegatte et al. (2007), p. 330.
[26] Cp. [174] Greenberg et al. (2007), p. 83ff.

3 OUTLINE OF DISASTER MANAGEMENT

3.1 Literature Review

For this thesis, relevant papers from the last 25 years, beginning with the publication year 1983, have been reviewed. The selection of papers was based on a current overview of disaster management related literature in the field of OR/MS (Operational Research/Management Science)[27] as well as a selection of papers published in OR-related journals, as indicated by the Journal Citation Report (JCR). From the journals specified in the JCR, relevant papers were found in the *Annals of Operations Research*, *Computers & Operations Research*, *Decision Support Systems*, *European Journal of Operational Research*, *Expert Systems with Applications*, *INFOR: Information Systems and Operational Research*, *Interfaces*, *Journal of Optimization Theory and Applications*, *Management Science*, *Mathematical Models of OR*, *Naval Research Logistics*, *Network & Spatial Economics*, *Omega – International Journal of Management Science*, *Operations Research*, *OR Letters*, *OR Spectrum*, *Optimization and Engineering*, *Reliability Engineering & System Safety*, *Safety Science*, *The Journal of the OR Society, Transportation Research Part B: Methodological*, *Transportation Research Part E: Logistics and Transportation Review*, and *Transportation Science*.

Keywords such as “disaster”, “catastrophe”, “extreme event”, “evacuation”, “emergency” and all different disaster types, e.g., “drought”, “earthquake”, “technological disaster”, “terrorism”, as well as the words “mitigation”, “preparedness”, “response”, and “recovery” were searched. Furthermore, investigations in the database ABI/Inform by the authors helped to find out the basic research directions in the field of disaster management, the above mentioned keywords have also been used here. Several disaster related journals, e.g., *Disaster Prevention and Management* and *Disasters* were reviewed in more detail and interesting papers were also found in *Health Care Management Science*, *Journal of Environmental Economics & Management*, *Medical Decision Making*, *Natural Hazards & Earth System Sciences,* and *Geomorphology*.

Furthermore, primary literature from the recent article of OR/MS research in disaster operations management by Altay and Green (2006) [93] was selected. Based on these papers,

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[27] Cp. [93] Altay and Green (2006), p. 475ff.

further research has been conducted in the journals *Mathematical & Computer Modelling*, *Journal of Contingencies & Crisis Management*, *Socio-Economic Planning Science*, and *Risk Analysis*.

The database Medline was used to find bioterrorism-related articles, here the keywords “bioterrorism”, “cost-effectiveness”, “smallpox”, “anthrax”, “spread”, “vaccination”, “response”, and a combination of the before mentioned words has been used. The following conferences were selected to get a deeper insight in the literature: *EURO 2006 XXI Island*, *XX ORPA 2007*, *EURO XVII 2000*, *IFORS 2005*, *IFORS 2002*, *YOR 15*, *OR 48*, *KMAC 2006*, and the *Winter Simulation Conferences*.

3.2 Classification of Disasters

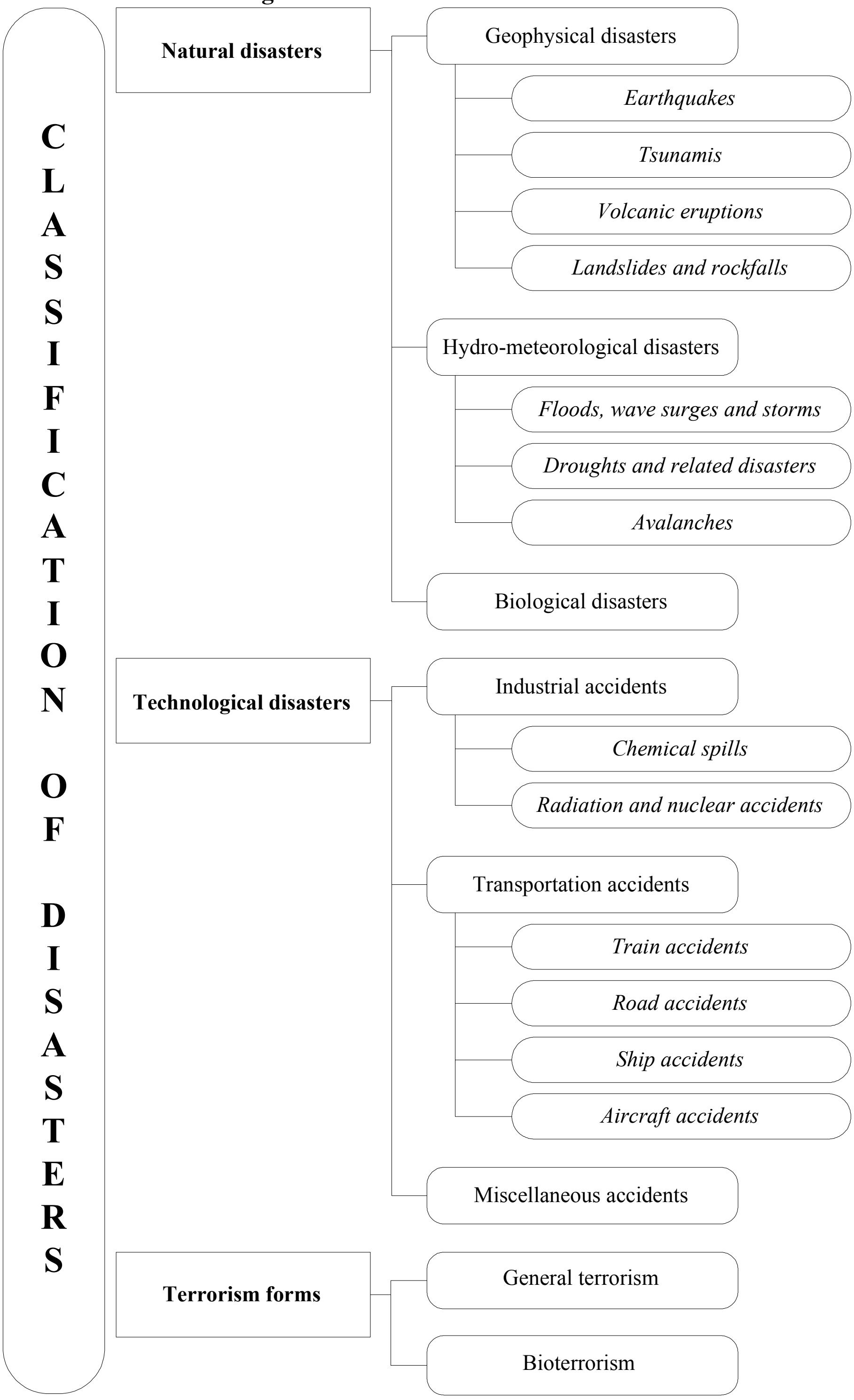
For this thesis, papers have been selected primarily from OR/MS related journals, as already mentioned in the previous section. In the following, the division of this paper will be organised according to the classification of disasters of the United Nations International Strategy for Disaster Reduction (UN/ISDR) (2002)[28,29]. A graphical illustration of the classification can be found in Figure 3.

Disasters are divided into natural and technological, i.e., man-made disasters; the section terrorism forms has been added due to the increasing number of attacks and higher vulnerability of countries to terrorist attacks. Natural disasters can, depending on their origin, be divided into geophysical, hydro-meteorological, and biological disasters.

Landslides and rockfalls, although they might have diverse causes, e.g., massive precipitation, snow melt, earthquakes, or volcanic eruptions[30] are added into the disaster class geophysical disaster for simplicity. More detailed descriptions of each category can be found in Section 4. Biological disasters, as they are epidemics, plant or animal contagion, and infestations[31] are above the scope of this thesis; interested readers are referred to an existent taxonomy about disaster management of highly-infectious diseases[32].

[28] Cp. [294] UN/ISDR (2002), p. 47 [access on October 5th, 2007].
[29] Cp. [228] Moe and Pathranarakul (2006), p.396f.
[30] Cp. [295] The National Atlas of the United States of America [access on April 24th, 2008].
[31] Cp. [294] UN/ISDR (2002), p. 47 [access on October 5th, 2007].
[32] Cp. [252] Seidelmann (2006), p. 1ff.

Figure 3: Classification of disasters



Source: Own illustration based on the [294] UN/ISDR (2002) and [228] Moe and Pathranarakul (2006)

Technological accidents are divided into industrial accidents, transportation accidents, and miscellaneous accidents. Although industrial accidents comprise chemical spills, radiation, collapses of industrial infrastructures, explosions, fires, and gas leaks[33], this thesis focuses only on the former two as they are well-represented in the literature.

[33] Cp. [294] UN/ISDR (2002), p. 47 [access on October 5th, 2007].

Various other kinds of classification of disasters can be found in the literature, as for example the division into natural, technological, and complex emergencies[34] or conventional, unexpected, intractable, and fundamental crises[35], but we focused on the classification of the UN as we found it the most appropriate for this purpose.
Besides that, disasters can furthermore be divided into short-notice and no-notice disasters. The first category encompasses disasters like hurricanes, flooding, and wild fires with a lead time of about 24 – 72 hours, the latter category are for example earthquakes or terrorist attacks, without any lead time[36].

3.3 Disaster Management Activities

"In the event of a disaster the primary task of the emergency manager is to ensure the safety and rapid evacuation of often many thousands of people to safety"[37]. The loss of lives should be minimized and the efficiency of the rescue operations should be maximized[38]. Disaster management is commonly described as consisting of five phases: prediction, warning, emergency relief, rehabilitation, and reconstruction[39].

To accomplish the objectives of these phases, the following activities are conducted, namely mitigation, preparedness, response, and recovery activities[40]. The first two types of activities can be classified as pre-event efforts and the latter two as post-event actions. Mitigation subsumes all activities and measures taken to prevent the onset of a disaster or to limit the effects in case a disastrous event occurs[41]. It includes structural and non-structural measures to reduce the impact of the various kinds of hazards[42].

The second group of activities, preparedness measures, help the community as a whole to be prepared to respond when a disaster emerges[43]. This encompasses the issuance of successful

[34] Cp. [231] O'Brien et al. (2006), p. 65.
[35] Cp. [179] Gundel (2005), p. 110ff.
[36] Cp. [22] Chiu and Zheng (2007), p. 710f.
[37] [134] De Silva and Eglese (2000), p. 423.
[38] Cp. [41] Haghani and Oh (1996), p. 231.
[39] Cp. [228] Moe and Pathranarakul (2006), p.396f.
[40] Cp. [93] Altay and Green (2006), p. 480.
[41] Cp. Ibidem.
[42] Cp. [294] UN/ISDR (2002), p. 28 [access on: October 5th, 2007].
[43] Cp. [93] Altay and Green (2006), p. 480.

early warnings and the temporary evacuation of people and property from the threatened area[44]. In this stage conducted drills and training cadre needs to be mentioned[45].

One of the measures taken after the disaster, response is the implementation of different emergency and resources procedures in order to preserve the life of human beings, property and the environment as well as the entire structure of the community, in a social, economic and political perspective. The last phase of disaster management is recovery, comprising long term actions taken after the immediate impact of the disaster so as to stabilize the affected region and to restore normalcy as far as possible[46]. „The timely availability of commodities such as food, shelter and medicine and effective transportation of the wounded affect the survival rate in affected areas"[47], and therefore efficient and timely interventions are the predominant goal for disaster managers. In Section 5.1, the classification of the papers into the abovementioned activities can be found.

3.4 Simulation as an Integrated Part of Disaster Management

Simulation is a crucial part for disaster management as it provides the necessary tools for the training or implementation of several constraints and conditions and makes a comprehensive representation of real-world settings during the disaster management process possible[48]. "In the context of incident management, simulations are suitable for training emergency managers and decision makers of involved agencies"[49] and gaming tools are useful as a training device for first responders[50]. Training costs related to simulation are considerably lower than costs for conventional live exercises, and various different new technologies can easily be tested via simulations[51]. A further advantage of simulations is that people can participate from different locations, so existing spatial and time-related boundaries can be overcome[52].

A significant part of the simulation-related literature deals with the so-called "Emergency Response Simulation", the consideration and integration of different aspects of the emergency

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[44] Cp. [294] UN/ISDR (2002), p.28 [access on October 5th, 2007].
[45] Cp. [209] Kim and Lee (1998), p. 191.
[46] Cp. [93] Altay and Green (2006), p. 480.
[47] [89] Yi and Özdamar (2007), p. 1178.
[48] Cp. [66] Patvivatsiri (2006), p. 501.
[49] [198] Jain and McLean (2005), p. 906.
[50] Cp. [198] Jain and McLean (2005), p. 906.
[51] Cp. [248] Robinson and Brown (2005), p. 919.
[52] Cp. [198] Jain and McLean (2005), p. 906.

process as for example the communication and coordination of the various entities involved[53]. In general, assumptions about the individual variables in the management process, e.g., number of victims, amount of resources, emergency services available, as well as further constraints may change the outcome of a model significantly[54].

A combination of gaming and simulation has been proven efficient for training of emergency managers[55]. "The capability to train responders and commanders together on a wide range of scenarios will enable development of effective emergency response teams"[56]. The proposed architecture is characterized by a high level of configurability and flexibility, but mechanisms for communication and synchronisation might be difficult to implement between the gaming and the simulation modules[57]. To provide a comprehensive analysis of different interrelated simulation, an analysis framework is a useful tool, creating a master scenario where all different steps in the process can be optimized[58].

The simulation of human cognitive behaviour and movement is useful to predict the possible impacts of these factors in times of catastrophes on the evacuation process of whole populations[59]. In order to incorporate crowd behaviour in the disaster management process, crowd simulations are used to get detailed information about the movement and density of the crowd in different circumstances[60]. Here, the usage of intelligent agents who have individual characteristics has been found useful[61]. Furthermore, crowd simulation is used so as to model evacuation of public transport terminals, e.g., airports[62].

Agent-based simulations have particularly been shown efficient as they simulate individual interactions and capture the resulting collective behaviour[63,64]. As the efficient transport of the casualties and the required resources is crucial, traffic simulations are implemented to simulate the traffic flow and specific vehicles movement in a predefined region under

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[53] Cp. [3] Albores and Shaw (2005), p. 888.
[54] Cp. [3] Albores and Shaw (2005), p. 891.
[55] Cp. [198] Jain and McLean (2005), p. 904.
[56] [198] Jain and McLean (2005), p. 912.
[57] Cp. [198] Jain and McLean (2005), p. 908.
[58] Cp. [243] Pollak et al. (2004), p. 839ff.
[59] Cp. [129] Court et al. (2004), p. 830.
[60] Cp. [199] Jain and McLean (2006), p. 495.
[61] Cp. [74] Shendarkar et al. (2006), p. 545ff.
[62] Cp. [23] Chow and Ng (2008), p. 244ff.
[63] Cp. [20] Chen and Zhan (2008), p. 25f.
[64] Cp. [281] Zarboutis and Marmaras (2007), p. 920ff.

different scenarios[65]. Health care simulations deal with the situation of the emergency department during the disaster response activities. This includes all actions taken for the treatment of the injured as well as the allocation of medical staff[66].

It has been shown useful to include simulation, modelling, and visualisation techniques into the disaster management process[67], especially 3-dimensional (3D) methods are important tools. Virtual reality gives first responders the opportunity to enter the (virtual) disaster zone and to train how to react in these situations[68,69].

Very often the discrete-event simulation (DES) has been used in disaster management literature[70,71,72]. As there is a strong need for effective information seeking and handling in disaster management, this kind of simulation may be useful in acquiring data on the information foraging process of emergency managers, to evaluate how changes in the contextual factors change the behaviour and to provide customized training[73]. Simulations initially developed for warfare purposes might also be applicable to emergency response situations. Through the use of high level architecture, which is generally used for war fighting simulation, the interoperability of two different simulation tools is facilitated, one of them simulating for example the detonation of a chemical weapon, the other modelling the evacuation of the population[74].

Simulation also occurs in the field of mass vaccination in case of the release of a biological agent[75]. For this kind of incidences, the release of a biological, chemical or nuclear agent, plume simulation is a helpful tool to model the dispersion of the emitting agent while considering the specific characteristics of the agent, weather conditions, and the surrounding area[76].

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65 Cp. [199] Jain and McLean (2006), p. 495.
66 Cp. [199] Jain and McLean (2006), p. 495.
67 Cp. [198] Jain and McLean (2005), p. 904.
68 Cp. [127] Corley and Lejerskar (2003), p. 1061ff.
69 Cp. [103] Beroggi et al. (1995), p. 79ff.
70 Cp. [72] Schenk et al. (2005), p. 936ff.
71 Cp. [177] Gu and Mendonça (2006), p. 554.
72 Cp. [79] Taaffe et al. (2006), p. 510.
73 Cp. [177] Gu and Mendonça (2006), p. 554ff.
74 Cp. [111] Bowers and Prochnow (2003), p. 1052ff.
75 Cp. [3] Albores and Shaw (2005), p. 887.
76 Cp. [199] Jain and McLean (2006), p. 494.

Furthermore, transportation simulation is applied in order to be able to incorporate the damages of the transportation infrastructure into the simulation system[77]. For the complexity of counterterrorism activities, analyses as for example complex adaptive systems and agent-based models have been proven to be appropriate[78]. The major shortcoming of complex simulations is the high amount of data required[79]. Simulation is also used to depict the information flow among parties after a disaster has occurred[80].

An integrated emergency response framework enables the use of simulation and modelling tools in an organized and structured way. It encompasses different simulation techniques and models, needed for the analysis of different incidents and their impacts on different entities of interest[81].

3.5 Disaster Management in Hospitals

Even at the hospital level, disasters may have a strong influence on the general management level. An optimal resource allocation in order to guarantee disaster preparedness in a hospital is inevitable. In a simulation of a hypothetical general terrorist attack leading to 500 additional patients within an hour it has been shown through a Multiple Fidelity Sequential Kriging Optimization that 19 additional doctors, 19 additional nurses, and 108 additional beds would be needed in a hospital to deal with this high increase in patients[82].

SIMULA, a simulation tool, is used to detect bottlenecks in the hospital in case of a sudden increase of the number of patients. Hence, hospital managers are able to test various scenarios and can evaluate the effectiveness of additional activities[83].

In particular bioterrorist activities may cause challenging situations in the emergency room (ER). In this case it is also crucial to have a management plan as adequate staff needs to be available in order to avoid long queues in the ER. The Simulation system FlexiSim allows adaptations in all parameters, the number of doctors, nurses and beds, as well as patient

[77] Cp. [199] Jain and McLean (2006), p. 496.
[78] Cp. [217] Loper and Presnell (2005), p. 895.
[79] Cp. [199] Jain and McLean (2006), p. 498.
[80] Cp. [248] Robinson and Brown (2005), p. 919ff.
[81] Cp. [197] Jain and McLean (2003), p. 1072ff.
[82] Cp. [72] Schenk et al. (2005), p. 936ff.
[83] Cp. [259] Stähly (1989), p. 231.

arrival times and other parameters. It has been shown that in this simulation a smaller number of doctors and nurses and a higher arrival rate of bioterrorism patients increase the duration of the patient's time in the ER[84].

However, there might also be situations in which the hospital itself has to be evacuated. This might for example occur when a hurricane threatens the hospital and the potential occurrence of the disaster is known in advance[85]. A hospital evacuation plan is therefore very important in order to ensure the rescue and relocation of the patients treated in the hospital as well as the medical staff. Also in this case, DES has shown to be a useful tool for the solution finding process. It has been found that not the evacuation of the building itself but the transportation of the patients creates the bottleneck in the process, and the number of critical care patients has the greatest impact on the total evacuation time[86]. In the literature, further papers with regard to the issues and complexities of hospital evacuation situations can be found[87].

3.6 The Role of Insurance in the Disaster Management Process

During the last decades, compensation payments for damage caused by natural disasters paid out by insurance companies worldwide has been increasing[88].

Two main strategies dealing with rare and dependent disastrous risk, namely risk reduction e.g., land use regulation or mitigation programmes, and risk spreading measures, e.g., insurances and financial markets can be identified[89]. Sometimes, however, "the nature of the events and the scale of the damage"[90] render encompassing insurance schemes impossible[91].

After a disaster has struck a region, the financing of new infrastructure needs to be assured. Ex-ante financing methods encompass insurance, catastrophe bonds, and other risk-transfer instruments, ex-post methods are borrowing and credit. The former methods increase a country's general stability but might abate the economic growth potential. Hence, a cost-benefit trade off exists between economic growth due to investment in new infrastructure and

[84] Cp. [66] Patvivatsiri (2006), p. 508.
[85] Cp. [262] Taaffe et al. (2005), p. 944.
[86] Cp. [79] Taaffe et al. (2006), p.509ff.
[87] Cp. [262] Taaffe et al. (2005), p. 943ff.
[88] Cp. [36] Fuchs et al. (2005), p. 893.
[89] Cp. [150] Ermoliev et al. (2000), p. 452.
[90] [269] Tsur and Zemel (2006), p. 422.
[91] Cp. [269] Tsur and Zemel (2006), p. 422.

additional solvency and stability for the country's economy[92]. These ex-ante financing methods, also called hedging instruments, might "create incentives for the mitigation of damage to public infrastructure"[93] in emerging or transition economies[94].

The deductible is also an efficient tool to encourage private loss mitigation. As after the disaster the insured person has to partly pay for the damage, interest in reducing future damages will increase. The amount of the deductible should ideally depend on the risk of the insured object[95]. Generally, insurance covers more than half of the costs related to natural disasters in developed countries, in developing countries less than 2% of the costs are absorbed by insurances[96]. „With increasing frequency, natural disasters are destroying infrastructure essential to economic development in developing and transition countries"[97], particularly people living in transition and developing countries are suffering from the occurrence of disasters as in these countries, per capita impact of disasters is almost 20 times higher than in the developed countries[98].

For the insurance industry forecasting of extreme losses caused by natural disasters has become more and more important during the last decades. A data-analytic method is used to forecast the related next record insured loss to property. This modelling of extreme losses has impacts on how insurances will manage catastrophic risk and decides upon the provision of appropriate financial protection[99]. In order to estimate the losses, extreme value theory is one of the most important methods to accomplish this task, increasingly also Bayesian methodology is included in extreme value analysis. After data normalization it has been shown that this method is useful as it provides reasonable forecasts[100].

The benefit of federal relief and insurance programmes for the community as a whole has been underlined in a study which shows that the provision of insurances for households in hazardous areas may also lead to non-monetary benefits for those people living in risk-free areas[101]. Insurances in general are also able to contribute to an increasing mitigation effort of

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92 Cp. [158] Freeman and Pflug (2003), p. 601.
93 [212] Kunreuther and Linneroth-Bayer (2003), p. 627.
94 Cp. [212] Kunreuther and Linneroth-Bayer (2003), p. 627.
95 Cp. [265] Thieken et al. (2006), p. 392.
96 Cp. [158] Freeman and Pflug (2003), p. 602.
97 [158] Freeman and Pflug (2003), p. 601.
98 Cp. [158] Freeman and Pflug (2003), p. 601.
99 Cp. [191] Hsieh (2004), p. 309.
100 Cp. [191] Hsieh (2004), p. 309ff.
101 Cp. [157] Frame (2001), p. 267.

the population living in hazard prone areas which on the other hand also increases the solvency position of insurers in the affected area[102]. Very often, people living in the hazardous area have a very low willingness-to-pay for mitigation measures, as their time horizon is too short or their budget constraint too severe or they are not aware of the increase in the property value of their building after having conducted the mitigation activities[103]. Encouraging of investment in mitigation measures can either be done by building codes, forcing the people to adjust their building to a certain standard, by premium reductions which are linked with long-term loans for mitigation activities or by lower deductibles for the part of the population which invests in the mitigation measures[104].

The insurability of risk and several different ways of managing catastrophic risks have been summarized in a system approach[105]. The increasing claims and damages cause challenges for the insurance industries, especially in developed countries[106].

How catastrophic risk influences technology transfer to developing countries has been evaluated in an empirical analysis[107]. It has been found that "natural catastrophic risk is negatively related to the extent of technological transfer taking place between developed and developing countries"[108]. Natural disasters have a positive impact on technology absorption only in countries with a higher level of GDP per capita, thus only richer countries benefit from this kind of Schumpeterian creative destruction[109]. Another cross-country empirical analysis has underlined the positive correlation among hydro-meteorological disasters and economic growth, human capital investment, and total factor productivity, though geophysical disasters are negatively correlated with growth[110].

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[102] Cp. [53] Kleindorfer and Kunreuther (1999), p. 727.
[103] Cp. [53] Kleindorfer and Kunreuther (1999), p. 733.
[104] Cp. [53] Kleindorfer and Kunreuther (1999), p. 734.
[105] Cp. [150] Ermoliev et al. (2000), p. 452.
[106] Cp. [229] Newkirk (2001), p. 159ff.
[107] Cp. [130] Crespo Cuaresmo et al. (2008), p. 12.
[108] [130] Crespo Cuaresmo et al. (2008), p. 12.
[109] Cp. [130] Crespo Cuaresmo et al. (2008), p. 1f.
[110] Cp. [256] Skidmore and Toya (2002), p. 682.

4 DISASTER MANAGEMENT LITERATURE RELATED TO CLASS OF DISASTER

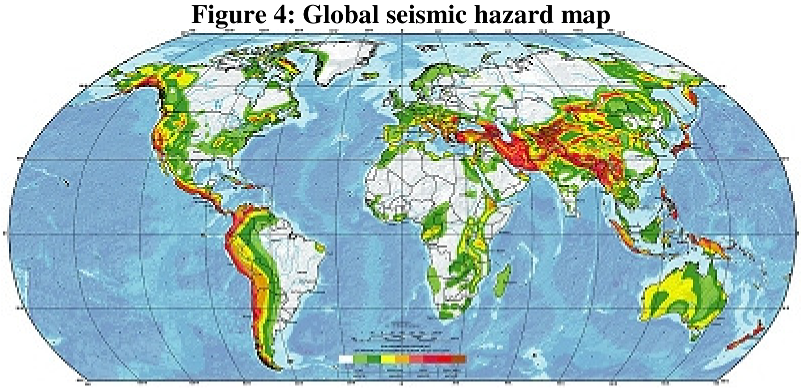
4.1 Natural Disasters

"Risk resulting from natural hazard is defined as a function of the probability of a hazard process and the related extent of damage"[111]. Some areas are per se more vulnerable to a specific disaster type than others. The management of natural disaster risk is broadly discussed in the literature, fuzzy entropy has been used to estimate the degree of risk in each area[112]. In the following, geophysical disasters and hydro-meteorological disasters are analyzed.

4.1.1 Geophysical Disasters

Geophysical disasters subsume all kinds of disasters related to natural earth processes or phenomena occurring in the biosphere[113]. The remainder of this section will focus on earthquakes, tsunamis, volcanic eruptions, as well as mass movements such as landslides and rock falls. Due to the geographic differences and structures in the earth's crust, some regions in the world are more prone than others. The global seismic hazard map[114] indicates the most endangered regions in the world.

Figure 4: Global seismic hazard map



Source: [292] Global Seismic Hazard Assessment Program: http://geology.about.com/library/bl/maps/blworldindex.htm [access on November 12th, 2007]

In Figure 4 the different hazard zones are shown, from white meaning no hazard, as the peak ground acceleration is very low, to dark red meaning very high hazard, as the peak ground

[111] [36] Fuchs et al. (2005), p. 893.
[112] Cp. [257] Spartalis et al. (2007), p. 260ff.
[113] Cp. [294] UN/ISDR (2002), p. 47 [access on October 5th, 2007].
[114] Cp. [292] Global Seismic Hazard Assessment Program [access on November 12th, 2007].

acceleration amounts to about 4.8 m/s². Within the next 50 years the respective site might expect a peak ground acceleration of 4.8 with 10 per cent probability. As can be seen in Figure 4 the Western part of America, the Middle East, as well as Japan and the islands in the South-Pacific are particularly endangered from seismic procedures.

4.1.1.1 Earthquakes

As earthquakes are very severe and cause immense damages in earthquake prone areas, a broad literature can be found focusing on various aspects of this natural disaster. As a lot of people have already been affected by an earthquake, there has been a need for researchers to develop models and simulations to enhance mitigation and preparedness efforts as well as response or recovery strategies.

The largest section of disaster-related literature has focused on mitigation strategies, as these interventions prevent disasters at first hand or reduce their impacts. Cellular automata have been used to simulate earthquake activity features[115]. In order to evaluate the cost-effectiveness of the mitigation strategies, the Strategy Effectiveness Chart (SEC) has been introduced to compare different mitigation approaches. The SEC gives information about the costs of implementation of the various strategies, identifies the amount of risk-reduction which can be attributed to each strategy, as well as the components of risk that are affected by the earthquake[116].

The enforcement of building structures is another mitigation tool, here a trade-off between potential future loss and costs for the retrofitting of houses, has to be found[117]. Especially in Southern European countries, building codes are less severe; therefore, a cost-benefit analysis has shown that building reinforcement significantly reduces structural damages when a moderate earthquake affects a region[118]. A case study conducted to analyze damage of buildings after an earthquake in Italy has shown that “damages to buildings are not simply related to the distance to the epicentre”[119] but depend on the local directions of the seismic forces[120].

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[115] Cp. [166] Georgoudas et al. (2007), p. 124ff.
[116] Cp. [40] Gupta and Shah (1998), p. 55.
[117] Cp. [28] Dodo et al. (2007), p. 2478ff.
[118] Cp. [50] Kappos and Dimitrakopoulos (2008), p. 53.
[119] [138] Di Spora and Patrizi (1987), p. 181.
[120] Cp. [138] Di Spora and Patrizi (1987), p. 181.

For the same purpose, mitigation, a document-indexing algorithm, KeyGraph is applied in order to extract active faults with a higher risk of near-future earthquakes from earthquake-sequences. The so-called Fatal Fault Finder assists in detecting interactions of fundamental and branch faults in a very large area and is therefore a useful earthquake mitigation tool[121].

Furthermore, reinforcement and rebuilding activities are studied in the literature so as to mitigate damages caused by earthquakes[122]. Here, particularly the structural vulnerability of bridges and tunnels has been considered[123]. To be prepared for an earthquake, the effective distribution of relief materials is important. Here, a minimization of transportation time and of the total costs is tried to be achieved[124].

In terms of response activities, the predominant goal is, as in every stage of the disaster management process, the reduction of fatalities. The performance of search-and-rescue is especially important in the first hours and days after the incident[125], especially the actions taken during the first three days after the earthquake are crucial for the social and economic magnitude of the quake[126]. Computer-based decision support systems (DSS) help to improve the overall accomplishment of disaster management activities.

One approach found in the literature deals with the assignment of available resources to operational areas after an earthquake; here the reduction of fatalities with the optimal allocation of existing resources forms the centre of interest[127].

Furthermore, also simulation systems such as the distributed simulation system EQ-Rescue have been developed in order to model the response activities after an earthquake. With the help of a multi-agent system, the resource allocation is simulated and a High Level Architecture is an adequate way to compute this complex system[128].

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121 Cp. [232] Ohsawa (2002), p. 119ff.
122 Cp. [104] Berrais (2005), p. 519ff.
123 Cp. [100] Bana e Costa et al. (2008), p. 442ff.
124 Cp. [81] Tzeng et al. (2007), p. 673.
125 Cp. [35] Friedrich et al. (2000), p. 41.
126 Cp. [159] Friedrich (2006), p. 486.
127 Cp. [35] Friedrich et al. (2000), p. 41.
128 Cp. [159] Friedrich (2006), p. 486.

The value function under risk has been found to be more appropriate than the expected utility theory for the evaluation of risk in a situation of a low probability and high consequence event[129].

Emergency logistics planning[130] needs to be further enhanced, as an effective logistic network is the only way to perform the supply of medical materials and personnel as well as food in a timely manner. After a disaster, infrastructure is at least partly destroyed, resources are even more scarce then usual and further restrictions, as for example a destroyed road network, need to be considered in the planning process. The vehicle routing problem is adapted to calculate the minimum total travel distance[131]. Transportation system performance studies focus especially on the road and railroad networks, showing a lower service restoration of Japanese road network compared to the railroad system[132].

The coordination of evacuation operations and logistics support after an earthquake has been done via an integrated capacitated location-routing problem. Here, it has been proven useful to not tracking each vehicle separately but as general integer flow variables[133]. Transportation planning in disaster response can also be conducted through a multi-commodity multi-modal network where arising uncertainties in the decision making process are given a special focus[134].

Furthermore, a quick reinstallation of sanitation services in earthquake hit areas is a very important response activity to prevent the outbreak of diseases related to inefficient hygienic standards[135].

In the literature there has also been pointed out that earthquake response strategies are even more difficult to implement on islands, as they are isolated from the mainland and the distance to emergency infrastructure is most likely higher than in mainland disaster

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[129] Cp. [80] Tamura et al. (2000), p. 467.
[130] Cp. [76] Sheu (2007), p. 687ff.
[131] Cp. [64] Özdamar et al. (2004), p. 219.
[132] Cp. [122] Chang and Nojima (2001), p. 486.
[133] Cp. [89] Yi and Özdamar (2007), p. 1191.
[134] Cp. [6] Barbarasoğlu and Arda (2004), p. 43ff.
[135] Cp. [241] Pinera et al. (2005), p. 227.

locations[136]. In addition, the strong population increase during the tourism season creates an even more challenging situation for emergency managers[137].

In order to analyze the flow of a homeless population after an earthquake to temporary state and later on its resettlement in a permanent residence, a mathematical model has been introduced. It has been pointed out that a considerable amount of families live in temporary accommodations for several years after a natural disaster[138].

Moreover, emergency construction and demolition waste management poses a severe problem for disaster relief management after strong earthquakes. From an economic perspective, it is efficient to combine the transportation of building waste and raw material in order to achieve economic savings as well as to recycle at least part of the building waste accruing because of seismic activity[139]. To optimize disaster relief after an earthquake, an optimal assignment of construction battalions has been developed[140].

4.1.1.2 Tsunamis

The devastating tsunami occurring in December 2004 lead to a tremendous increase in the scientific analysis of this phenomenon. Suddenly, the lack of a Tsunami Early Warning System in the Indian Ocean had a devastating consequence[141,142]. Over 220,000 people have been killed in Indonesia, Sri Lanka, India, and Thailand and over 2.4 million people have been affected by the disaster[143].

In order to determine the overall effects of the Tsunami of December 26, 2004, on the landscape, Remote Sensing (RS) seems to be a very effective tool[144]. A neural network technique has been used to quickly be able to provide sufficiently detailed pictures of the affected region, displaying the accessibility of every single area[145].

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[136] Cp. [136] Delladetsima et al. (2006), p. 470.
[137] Cp. [136] Delladetsima et al. (2006), p. 483.
[138] Cp. [63] Nikopoulos and Tzanetis (2003), p. 562ff.
[139] Cp. [215] Lauritzen (1998), p. 45ff.
[140] Cp. [15] Brown and Vassiliou (1993), p. 1ff.
[141] Cp. [213] Kurita et al. (2006), p. 93.
[142] Cp. [208] Kelman (2006), p.178.
[143] Cp. [291] EM-DAT [access on June 5th, 2008].
[144] Cp. [91] Aitkenhead (2007), p. 217.
[145] Cp. [91] Aitkenhead (2007), p. 224.

Tsunami warning systems usually include detectors, and the provision of adequate warning through these instruments is called the tsunami warning potential. This potential is dependent on the number of detectors used and the response time of disaster managers[146].

Even after several years, the inbound tourism in Thailand has not recovered from the causality[147]. Cash for work programmes implemented in Indonesia have been shown effective in empowering displaced population to return in their home communities. These programmes infuse cash into the destroyed economic environment and have a positive impact on recovery activities[148]. The implementation and perpetuation of buffer zones should avoid another catastrophe of the same amplitude[149].

A further study concentrated on the characteristics of a tsunamigenic earthquake taken place in Tockachi-Oki in order to try to understand the dynamical processes taking place in the tsunami source. A 3D dynamical model was developed for the description of water layer dynamics in a tsunami event but as certain features were neglected in the model, the real situation could not be precisely modelled[150].

The generation of tsunami waves is of special interest, in the literature for example the hydrodynamical model can be found describing the generation of those waves[151].

In tsunami-prone areas, the location planning for public facilities, e.g., schools, is a challenging task, as the risks of inundation by tsunamis has to be included in the decision making process[152].

Apart from the high tsunami risk in the Pacific area, researchers have focused on the evaluation of past tsunami incidences in the Mediterranean Sea to derive potential future tsunami threat in Southern European coastal areas. The respective country-specific tsunami catalogues have been updated. In the central Adriatic Sea, two tsunamigenic earthquakes occurred in 1916 and 1930, thus, the total number of tsunamigenic earthquakes in this region

146 Cp. [113] Braddock (2003), p. 225ff.
147 Cp. [194] Ichinosawa J. (2006), p.111.
148 Cp. [142] Doocy et al. (2006), p. 277ff.
149 Cp. [213] Kurita et al. (2006), p.109.
150 Cp. [230] Nosov and Kolesov (2007), p. 243 ff.
151 Cp. [147] Egorov (2007), p.65.
152 Cp. [140] Doerner et al. (2008), p. 1ff.

in the 20th century raises from three to five[153]. Strong tsunamis in the Eastern Mediterranean have a recurrence of 142 years[154].

4.1.1.3 Volcanic Eruptions

With regard to natural disasters caused by volcanic eruption, the models and approaches in the literature mostly deal with mitigation strategies of the world's most active volcanoes, as for example the Merapi volcano in Indonesia, Java, the Vesuvio in Italy, or other active volcanoes in Latin America. Facing the potential threat of a volcanic eruption, strategic land use planning such as in Naples, is one of the most promising mitigation tools[155].

Hazard-zone maps are a very important tool to underline the vulnerability of the region surrounding the volcano. Considering the Merapi volcano, affecting at least 440,000 persons in case of an outbreak, it has been shown that the hazard-zone map needed to be revised[156]. A vast amount of measures are used to simulate different scenarios to be able to forecast pyroclastic and lahar flow and to outline the most endangered regions. A numerical simulation which has been based on a Digital Elevation Model, a stereo-pair of satellite images, and one 2-dimensional (2D)-orthoimage were used in order to enhance the mitigation strategies in this densely populated area of the world[157].

One major threat in case of a volcanic eruption is the formation of pyroclastic density currents, i.e., clouds of erupted particles and gases, and their impacts on residual buildings in the hazardous area. Therefore, the vulnerability of buildings and occupants has been evaluated and the different characteristics of the pyroclastic density currents such as the temperature and speed but also the features of the buildings have been modelled. It has been shown that as mitigation measures in urban areas, the amount of potential missiles has to be reduced, window glass to be strengthened, and the installation of shutters reinforced to reduce casualties related to broken window glass[158].

Mudflows consisting of volcanic ash create another threat for residual communities in threatened areas as they easily impede natural water channels. For the Mount Pinatubo on the

[153] Cp. [219] Maramai et al. (2007), p. 15ff.
[154] Cp. [233] Papadopoulos (2007), p. 57.
[155] Cp. [268] Torrieri et al. (2002), p. 95ff.
[156] Cp. [266] Thouret et al. (2000), p. 479ff.
[157] Cp. Ibidem.
[158] Cp. [258] Spence et al. (2007), p. 219ff.

Philippines, which caused considerable loss through its eruption in 1991, a statistical model has been created in order to model, assess and manage the risk of volcanic ash flow. In a scenario it has been shown that a policy with large investments at the first stage and a small amount of investments in the following stages leads to the lowest total amount of uncontrolled sediments given a predefined mitigation budget level[159].

4.1.1.4 Landslides and Rockfalls

In the field of landslides hazard assessment and landslide susceptibility analysis and zonation[160], the evaluation of run-out areas and reasonable land-use planning[161] is of similar importance as the hazard-zone for volcanoes. Landslide inventory maps are a useful tool to "understand the evolution of landscapes, and to ascertain landslide susceptibility and hazard"[162]. A Geographic Information System (GIS) might be a useful tool for mapping landslide risks[163]. Furthermore, the vulnerability of buildings to landslides needs to be assessed in hazardous areas[164].

A dynamic analysis model has been proven successfully in the simulation of the behaviour of landslides, the run-out distances, velocity, and debris thickness[165]. The flooded paddy field effect has been well studied, stating that the presence of these fields "in valley bottoms may enhance the travel distance of flow-type landslides"[166].

4.1.2 Hydro-Meteorological Disasters

The second category of natural disasters are hydro-meteorological disasters, these are "natural processes or phenomena of atmospheric, hydrological or oceanographic nature"[167]. In the following sub-sections, floods, wave surges, and storms, droughts, related disasters, as well as avalanches are discussed.

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[159] Cp. [57] Leung et al. (2003), p.1323ff.
[160] Cp. [222] Melchiorre et al. (2008), p. 379.
[161] Cp. [249] Ruff and Czurda (2008), p. 314.
[162] [163] Galli et al. (2008), p. 268.
[163] Cp. [246] Remondo et al. (2008), p. 496.
[164] Cp. [234] Papathoma-Köhle et al. (2007), p. 765ff.
[165] Cp. [152] Evans et al. (2007), p. 95.
[166] [152] Evans et al. (2007), p. 99.
[167] [294] UN/ISDR (2002), p. 47 [access on October 5th, 2007].

4.1.2.1 Floods, Wave Surges and Storms

In the literature, flood management measures are divided into structural measures, e.g., engineering provisions such as storage reservoirs, levees, flood walls, channel improvements, and non-structural measures, as they are flood proofing and plain zoning, land use warning, warning up to rehabilitation activities, as well as flood insurance[168]. Spatial information technologies, as for example the GIS and RS are widely used in studies of flood management[169].

So called nowcasting systems enter a new feature, namely the estimation of rainfalls into the flood management process. That way, estimated flood inundation maps can be created, forming the basis of advanced flood warning[170]. Moreover, knowledge-based models facilitate the entire knowledge acquisition process supporting emergency managers[171].

Another approach in the literature has shown that artificial neural networks are an essential tool for flood disaster prediction, especially when the problem is ill-structured, as it is generally the case when a flood disaster occurs[172]. "Extreme value theory provides simple techniques for estimating probabilities of future extreme levels of a process given historical data"[173]. This method is used in order to show whether a flooding event in 1999 in Venezuela might have been anticipated beforehand due to daily rainfall measurements. Adding a Bayesian model the study found that the extreme value of the rainfalls could have been expected before the disaster occurred[174].

For storm water drainage management in France, a multicriteria approach based on a survey has been applied, assisting to rank various alternatives according to best management practice. This tool helps take all the different viewpoints and focuses of the various stakeholders into consideration[175].

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[168] Cp. [151] Esogbue (1996), p. 170.
[169] Cp. [107] Billa et al. (2004), p. 356f.
[170] Cp. [107] Billa et al. (2004), p. 362.
[171] Cp. [189] Hernández and Serrano (2001), p. 178.
[172] Cp. [275] Wei et al. (2002), p. 383ff.
[173] [125] Coles and Pericchi (2003), p. 405.
[174] Cp. [125] Coles and Pericchi (2003), p. 415f.
[175] Cp. [220] Martin et al. (2007), p. 338 ff.

Fuzzy set theory is also used to model the optimal control planning for floods and storm water. Here, costs are already implemented in the mathematical model[176].

Nonetheless, sometimes relocation of populations seems to be the preferred hazard mitigation measure in flood prone areas, particularly when the threat of a natural disaster is particularly high and protection is hardly feasible or when economic costs related to other mitigation tools are very high[177]. Besides that, the role of unofficial flood warning systems should not be underestimated[178].

Emergency logistics planning for an eventual flooding event is important to define the "structure of rescue organizations, locations of rescue resource storehouses"[179] and the allocation and distribution of rescue resources[180].

In times of flooding, it is important to effectively manage water capacity in single water retention reservoirs to minimize damages downstream the reservoir[181].

With regard to hurricanes, the recent most devastating disaster has been Hurricane Katrina, which caused approximately USD 200 billion in property damage, over 1,800 victims and over 500,000 displaced people[182]. The bureaucratic system of disaster management failed in the aftermath of this extreme event[183]. The low median income of New Orleans residents and the associated lack of insurance aggravated the situation for the affected population[184].

A study evaluating hurricane effects on social and economic damage has shown that although the average number of fatalities due to hurricanes has fallen from 0.5 per million residents in the 1950s to 0.05 per million in the 1990s, the economic damage caused by hurricanes has strongly increased during the last decades[185]. More people are willing to live in coastal, hurricane prone areas, as their standard of living is rising, the probability of such an event is

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[176] Cp. [151] Esogbue (1996), p. 178f.
[177] Cp. [238] Perry and Lindell (1997), p. 49.
[178] Cp. [235] Parker and Handmer (1998), p. 45ff.
[179] [18] Chang et al. (2007), p. 737.
[180] Cp. [18] Chang et al. (2007), p. 737.
[181] Cp. [205] Karbowski et al. (2005), p. 599ff.
[182] Cp. [274] Watkins (2007), p. 477.
[183] Cp. [264] Takeda and Helms (2006), p. 408.
[184] Cp. [274] Watkins (2007), p. 481.
[185] Cp. [128] Cornell Sadowski and Sutter (2005), p. 422.

low and subsidized insurances are offered[186]. Furthermore, as federal or state governments are paying a large fraction of the damages caused by hurricanes, "local governments have little incentive to control land-use development in ways that may reduce hurricane damage potential"[187].

It has been found that a decrease in lethality has a statistically significant positive impact on the amount of economic damages[188]. Another study focusing on the effects of hurricanes on the housing market in Lee County has shown that even in areas not directly affected by the hurricane (i.e., near-miss areas) the loss in property values was approximately 19 percent[189]. Especially for hurricane evacuations, a DSS was developed to estimate the overall effects on the transportation network and to assess evacuation time[190].

General public cost estimation methods are used in order to redistribute the costs related to mitigation up to recovery strategies for hurricanes away from the general taxpayer and toward the population that depend most likely on these disaster management services to generate general revenues more equitably[191]. The application of the model to Lee County, Florida indicated that estimated total local response and recovery costs vary from USD 4.7 million for a category 1 hurricane, i.e., up to 137 km/h of speed to USD 130 million for category 5 hurricanes, i.e., up to 265 km/h of speed[192].

With the calculation of expected annual losses the optimal mitigation strategy for wood-frame houses in times of hurricanes in seven counties in the USA has been tried to find out. From the seven mitigation strategies evaluated, namely retrofitting, building enforcement, technology diffusion, retrofitting (at two different levels), building inspection, increasing durability of components, and restricted land use in hazard prone areas, retrofitting reduced the relative expected annual loss considerably compared to all other strategies[193]. As a preparedness strategy, a simulation was used to evaluate potential losses of differently strong hurricanes and to find out the number of persons potentially seeking shelter after the

[186] Cp. [128] Cornell Sadowski and Sutter (2005), p.423.
[187] [109] Boswell et al. (1999), p. 360.
[188] Cp. [128] Cornell Sadowski and Sutter (2005), p. 431.
[189] Cp. [182] Hallstrom and Smith (2005), p. 541.
[190] Cp. [270] Tufekci (1995), p. 39ff.
[191] Cp. [109] Boswell et al. (1999), p. 361.
[192] Cp. [109] Boswell et al. (1999), p. 366.
[193] Cp. [49] Jain and Davidson (2007), p. 55f.

disastrous events. Simple tools like boards to cover the windows have been proven to be more effective than an overall evacuation strategy[194].

4.1.2.2 Droughts and Related Disasters

"Drought is the consequence of a natural reduction in the amount of precipitation during an extended period of time"[195], its onset difficult to determine and the spread of this natural disaster is a large geographic area[196]. For the Sub-Saharan countries, a ten step planning process may be implemented to change the reactive attitude towards drought into activities that focus on mitigation and early warning systems[197].

Planning of water-resource management systems under uncertainty is a wide field of research in the literature. One approach is an interval-parameter fuzzy two-stage stochastic-programming method, which is able to insert pre-defined water policies into the optimization process and it incorporates system uncertainties into the solution-finding process[198]. In a case study, several scenarios have been analyzed, showing that in case of insufficient water supply, municipality should be served first, then the industry and lastly water should go to the agricultural sector, taking into consideration the net benefit when water demand is satisfied as well as the penalty if it is not satisfied[199].

Over-pumpage of water in Israel has led the researchers' focus on the optimal development of marginal water sources, in order to meet future demand of potable water. These marginal water sources encompass treated wastewater, runoff water, and saline groundwater, differing in the capital intensity. The case study shows that at most sites, the implementation of facilities for saline ground water and treated wastewater is economical[200].

Another study deals with the problem of drought in a large urban water district. The authors determine the least-cost combination of measures to be taken into account in terms of periodic water shortage. It has been found that the construction of new water storage capacity is not the

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[194] Cp. [29] Drake et al. (2007), p. 1ff.
[195] [276] Wilhite (2000), p. 82.
[196] Cp. [276] Wilhite (2000), p. 81f.
[197] Cp. [276] Wilhite (2000), p. 91.
[198] Cp. [218] Maqsood et al. (2005), p. 208.
[199] Cp. [218] Maqsood et al. (2005), p. 218.
[200] Cp. [14] Brimberg (1995), p. 35ff.

cheapest alternative, it is more cost-efficient to focus on a combination of conjunctive water use (i.e., surface and groundwater supplies) and water marketing[201].

The other aspect related to water management in times of drought is demand management. Water rationing based on the volumes of reservoir storage and the projected inflow was calculated, minimizing the number of months where rationing is required[202]. In arid areas there is also a high probability that bush or wildfires occur. The global "objective of forest fire control is the minimization of fire's negative impact on human beings, private and public property, and natural resources"[203].

The assessment of forest fire danger is the starting point to be aware of the potential hazard[204]. Stochastic fire growth models are used to predict the behaviour of large forest fires[205].

In order to deal with the occurrence of wildfires, agent-based simulations are useful and a combination of fire fighting and fire spread simulation incorporates all important features of these situations. Fire fighting units are considered as mobile agents and they are coupled with a specific cell, these couplings can be modified during simulation. A discrete time modelling has been shown to be appropriate to accomplish the simulation[206].

A GIS coupled with mathematical programming and simulation has been shown to be a flexible tool to assist decision makers in Greece in case of a forest fire. That way, geographic information about the terrain, availability of fire fighting resources in the right position and the ability of employing these data in different scenarios are bundled, leading to more efficient forest fire management[207].

The simulation of wildland fires is the main objective of Dynamic Data Driven Application Systems. In these systems, a wildfire behaviour model and a numerical weather prediction model are combined and their interrelatedness is given special attention. That way, the interactions between a large-scale fire and the atmosphere can be modelled. Data used in the

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201 Cp. [33] Fisher et al. (1995), p. 304.
202 Cp. [77] Shih and ReVelle (1995), p. 174.
203 [27] Dimopoulou and Giannikos (2004), p. 477.
204 Cp. [278] Wybo et al. (1995), p. 61ff.
205 Cp. [112] Boychuk et al. (2007), p. 9ff.
206 Cp. [192] Hu et al. (2005), p. 248ff.
207 Cp. [27] Dimopoulou and Giannikos (2004), p. 476ff.

models are collected by fixed ground-sensors or from images taken by planes or satellites[208]. Integrated spatial DSS are also often used for wildland fire fighting[209].

A system applied in Galicia, Spain, encompasses a forest fire risk prediction model, a backup of the monitoring and extinction phase as well as a planning tool for the recuperation of the affected area[210]. Forest fire risk estimates are also conducted for Greece[211]. Furthermore, telegeoprocessing and intelligent software concepts are useful tools in forest fire management[212].

For effective response to wildland fires, the optimal deployment of fire engines has been evaluated for California[213] and in Ontario, the deployment of airtankers has been studied[214].

4.1.2.3 Avalanches

In mountainous regions such as Switzerland it is especially important to be prepared for avalanches. In the Alpine region, there exist avalanche hazard maps in order to prevent significant monetary losses. Approaches in the literature have shown that the calculated run out distances of avalanches are very sensitive to the underlying model assumptions and a slight change of these assumptions might have strong impacts on the avalanche hazard maps, as these are based on the calculated run-out distances[215]. The linking of a Bayesian network to a GIS has been shown to be able to enhance the understanding of interdependencies of the decisions and processes involved as well as it is a supportive tool for decision makers for the risk assessment in avalanche prone areas[216].

Further studies in the area of Davos, Switzerland, have shown that, depending on the initial setting and scenarios, denser forests and higher timberlines may lead to benefits up to CHF 8 million in terms of avalanche protection, which highly exceeds forest maintenance costs of approximately CHF 140,000[217].

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[208] Cp. [143] Douglas et al. (2006), p. 2117ff.
[209] Cp. [178] Guarniéri and Wybo (1995), p. 3.
[210] Cp. [92] Alonso-Betanzos et al. (2003), p. 545ff.
[211] Cp. [195] Iliadis and Spartalis (2005), p. 747ff.
[212] Cp. [196] Jaber et al. (2001), p. 3ff.
[213] Cp. [42] Haight and Fried (2007), p. 31ff.
[214] Cp. [59] MacLellan and Martell (1996), p. 677ff.
[215] Cp. [176] Grêt-Regamey and Straub (2006), p. 911.
[216] Cp. [176] Grêt-Regamey and Straub (2006), p. 922.
[217] Cp. [39] Grêt-Regamey et al. (2007), p. 7.

In the municipality of Davos, a cost-benefit analysis of technical mitigation measures, as they are stoneworks, mixed terraces, and snow rakes, has been conducted in order to evaluate their social net-benefits. The total expenditure for avalanche mitigation measures amount to EUR 1 billion in the period of 1950 to 2000[218]. The study analyzed whether or not the past investments in avalanche mitigation have caused net economic benefit and used the actuarial concept for the calculation of the probable maximum loss (PML). A cost-benefit ratio of 1:10 has been found for endangered buildings and 1:30 for the residential population, varying for the individual avalanche paths and the areas affected. Concerning the spending by the Confederation the costs of the avalanche countermeasures are twice as high as the expected future tax revenue, hence in the municipality of Davos the mitigation measures taken can be regarded as being subsidies for habitation in avalanche prone areas[219].

Another study has engaged in the long-term development of value-at-risk (VaR) in the avalanche prone areas Davos in Switzerland and Galtür in Austria. An analysis of damage potential has shown comparable socio-economic changes in the last century in both areas. Population and the number of buildings increased and mitigation measures increasingly protect the areas[220]. Peaks in the population due to winter tourism must also be taken into consideration[221].

4.2 Technological Disasters

Technological disasters are so-called man-made disasters. Various approaches exist in the literature to define these disasters by the number of casualties, economic loss, or overall environmental impact[222]. Literature not related to a specific type of technological disasters will be summarized below.

Technological disasters might be prevented or at least less likely, if there would exist an inspection plan for critical multi-characteristic components such as parts of an aircraft or a complex gas ignition system. During inspection, misclassifications might occur stating that a component still is usable even if it is not, or inversely. Therefore, a mathematical model is

[218] Cp. [261] SLF (2000) cited in [37] Fuchs and McAlpin (2005), p. 319.
[219] Cp. [37] Fuchs and McAlpin (2005), p. 326f.
[220] Cp. [36] Fuchs et al. (2005), p. 899f.
[221] Cp. Ibidem.
[222] Cp. [253] Shaluf et al. (2003), p. 305.

created to "determine the optimal inspection plan and the optimal number of repeat inspections that minimizes the expected total cost"[223].

Another study focuses on the job scheduling problem in a contaminated area such as after a nuclear or chemical spill. In this case, dynamics of the harmful factor of the chemical or radiation have to be taken into consideration as well as their impact on the recovery of the organism of the responders in the rest periods[224].

Beyond that the optimal investment strategy of a firm facing possible technological accidents has been evaluated. There exist situations in which it can be optimal for a small firm to expand to be able to pay for the damage caused by a disastrous accident. It has been shown that larger firms with a higher capital stock spend more money on safety[225].

Evacuation of an offshore structure might be necessary because of the outbreak of a fire or an explosion or because of structural damage following a collision with a vessel. Even though there is a lack of data of past incidences it has been shown that the deployment of rescue crafts considerably reduces the evacuation time especially under harsh weather conditions[226]. A decision modelling tool has been designed to model decisions people make in offshore emergencies[227].

In the following sub-sections, the management of industrial accidents, transportation accidents, and miscellaneous accidents are reviewed.

4.2.1 Industrial Accidents

In the field of industrial accidents, chemical spills, and radiation, i.e., nuclear accidents are analyzed.

4.2.1.1 Chemical Spills

"The number of catastrophic oil spills in recent years has demonstrated the need for effective response management"[228] to minimize the disastrous consequences for the environment. The

[223] [30] Duffuaa and Khan (2002), p.1016.
[224] Cp. [200] Janiak and Kovalyov (2006), p. 131.
[225] Cp. [185] Hartl et al. (1999), p. 99ff.
[226] Cp. [62] Mould (2001), p. 401ff.
[227] Cp. [141] Doheny and Fraser (1995), p.17ff.
[228] [78] Srinivasa and Wilhelm (1997), p. 554.

major oil spill disasters in the recent years are the spill of Exxon Valdez in Alaska in 1989 and the accidents of the tankers Erika in France in 1999 and Prestige in Spain in 2002[229]. Therefore, it is extremely important to prepare disaster management plans for the case of a chemical spill, especially oil spills, and to keep in mind the prevalent factor time in the problem[230]. Particularly after oil spills timely interventions are to favour as shoreline clean-up is very costly and the damage of the coasts is considerable[231].

In case of an oil spill several factors influence the oil spill cleanup costs: 1) the type and amount of the oil, 2) the exact location of the spill, and 3) general characteristics of the affected area[232].

A study which particularly focuses on preventive measures against marine pollution also takes into account the objective function of the vessel owner, namely to maximize expected profits. Depending on the frequency of harbour patrols vessel owners should be enforced to fulfil technological standards as otherwise they would have to pay penalties, thus "minimizing the expected volume of oil spilled is equivalent to minimizing the social damage"[233]. Recapitulatory the model allows predicting the approximate number of spills per ship and the amount of oil spilled during the transfer process from the ship to the harbour facility[234].

Oil spill clean up operations include mechanical operations, chemical dispersants, burning, and bioremediation, in most of the cases a combination of several of these techniques is used in order to respond effectively. In the literature, the term equipment set is very often used, stating that several individual oil spill components are used as an entity[235]. A general integer programme with the objective of minimizing total response time may be a useful decision support aid for emergency managers to react to an oil spill[236] and to locate and store response facilities in an effective way[237].

For the Galveston Bay Area, a model to minimize total cost for new equipment for oil spill response, e.g., build new or expand existing storage location for equipment or to buy new

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[229] Cp. [83] Vanem et al. (2008), p. 1354.
[230] Cp. [78] Srinivasa and Wilhelm (1997), p. 556.
[231] Cp. [10] Belardo et al. (1984), p. 1184f.
[232] Cp. [83] Vanem et al. (2008), p. 1358.
[233] [171] Gottinger (1998), p. 21.
[234] Cp. [171] Gottinger (1998), p. 29.
[235] Cp. [69] Psaraftis and Ziogas (1985), p. 1478.
[236] Cp. [78] Srinivasa and Wilhelm (1997), p. 570.
[237] Cp. [46] Iakovou et al. (1996), p. 72ff.

components and pre-position them on neuralgic points, has been implemented. An area-wide contingency plan has been created which might be a decision aid for several parties, as for example shipping companies, contractors, or various state agencies[238].

The question of optimal location of oil spill response equipment has furthermore been addressed by using a partial set covering model. The model has been applied in the Long Island Sound and depending on the assumptions made either a central storing facility or several different storing sites for the response equipment are proposed[239].

Besides the optimal location of the equipment the optimal dispatching of oil spill cleanup equipment is another crucial factor for effective oil spill response activities[240].

Measures for the detection of oil pollution, especially the case of illegal oil dumping in the sea, have been evaluated via a cost-benefit analysis. It has been shown that satellite control reduces pollution and decreases monitoring costs compared to aerial monitoring with airplanes. That way, suspicious tankers can be identified with the satellite and planes are only used for the detailed inspection of the surrounding of the identified tanker[241].

A cost-effectiveness analysis has tried to find out which mitigation measures are the most effective. Due to a global average cleanup cost estimation of USD 16,000 per tonne of oil spilt it has been found that only double hulls and certain vessel response plans are not cost-effective[242].

Furthermore, approaches in the literature can be found dealing with the sudden release of toxic substances into the environment. It has been shown effective to categorize the spills into a finite number of groups to assign an estimate of damage to each of the groups. An example of an oil spill in the St. Lawrence River has approved that even one spill is enough informative for a proper analysis of the effects of such a spill[243]. A Dynamic Data Driven

[238] Cp. [87] Wilhelm and Srinivasa (1996), p. 795.
[239] Cp. [10] Belardo et al. (1984), p. 1194.
[240] Cp. [69] Psaraftis and Ziogas (1985), p. 1475ff.
[241] Cp. [155] Florens and Foucher (1999), p. 81 ff.
[242] Cp. [83] Vanem et al. (2008), p. 1364f.
[243] Cp. [201] Jenkins (2000), p. 275 ff.

Application System is also used to track contaminants in water, the sensors use near-infrared, visible, and ultraviolet light[244].

The evacuation process after a hazard at an industrial site is special, as not only the evacuation time but the dose of the chemical received by the population have to be considered[245].

The implementation of Chemical Emergency Operational Centres in Greece should improve the ability to cope with large chemical accidents. In this centre, databases of historical chemical accidents and information about chemical substances are combined with GIS information. Case studies have shown that this organisational entity provides very useful information for decision makers regarding the estimates of the extent and attributes of an accident[246].

In order to support inter-organisational coordination in the management of hazardous material (hazmat) an interactive intelligent spatial information system has been developed. A community-wide knowledge base is the objective of this system in order to make inter-organizational decision support feasible[247].

4.2.1.2 Radiation and Nuclear Accidents

Nuclear accidents form a very hazardous threat. Therefore, quick response is the superior objective in these events. As nuclear accidents affect a large number of people and the decision making in this field has strong social and political impacts, there is a need to enhance communication among parties, reduce the risk of misunderstandings, and improve the decision making process as a whole. Multiattribute risk analysis is useful to enhance decision making quality in case of a nuclear accident as it is a structured and systematic approach which gives the decision maker a better understanding of the problem and provides and makes the entire process transparent and reconstructable[248]. To predict future risk of a higher severity accident, experience of both small and larger nuclear accidents should be taken into consideration[249].

[244] Cp. [143] Douglas et al. (2006), p. 2120.
[245] Cp. [38] Georgiadou et al. (2007), p. 1388ff.
[246] Cp. [211] Kourniotis et al. (2001), p. 60.
[247] Cp. [126] Comfort et al. (2001), p. 144ff.
[248] Cp. [184] Hämäläinen (2000), p. 457ff.
[249] Cp. [124] Chow et al. (1990), p. 265ff.

As a mitigation strategy it is required to train first responders on how to react in case of a nuclear disaster. The development of an advanced visualisation and simulation tool, where they can train in a safe virtual environment, aims to improve responders' response activity and familiarity with devices such as the Geiger counter as well as it reduces overall training costs[250].

Furthermore, the irreversibility effect is applied in disaster management literature to evaluate the evacuation decision in an industrial area threatened by the possibility of a nuclear accident. This means that a decision maker, who does not take into consideration the possibility of getting more complete information in a latter stage of the decision making process before making future decisions, will take the irreversible decision of evacuating the industrial area too easily. In the model it is assumed that the decision maker is rational and tries to minimize total expected cost[251]. It has been found that higher initial evacuation costs of the industrial area will lead to a longer decision-finding period of the decision maker, on the other hand higher additional evacuation and health effect costs will lead to an earlier decision of the decision maker. As the probability of an actual nuclear spill rises, also the speed of the decision making process increases[252].
Evacuation processes might be especially challenging in case of a nuclear accident, therefore it is particularly important to evaluate evacuation routes, estimate the evacuation time and figure out potential bottlenecks in the system[253].

Emergency managers face a highly complex situation and DSS are needed in order to assist the decision making process. A Real-time Online DSS, RODOS, helps eliminate decision alternatives which do not satisfy different constraints and therefore reduces the complexity of the problem, displaying only feasible strategies[254].

DSS link various tools to be able to deal with complex situations, as for example the ETH-NUKERISK combines the GIS with logical and mathematical modelling for forecasting environmental damage and overall health effects of a nuclear incident[255].

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[250] Cp. [250] Sanders and Lake (2005), p. 914f.
[251] Cp. [236] Pauwels et al. (2000), p. 25ff.
[252] Cp. [236] Pauwels et al. (2000), p.47f.
[253] Cp. [44] Hobeika et al. (1994), p. 22ff.
[254] Cp. [65] Papamichail and French (1999), p. 617.
[255] Cp. [167] Gheorghe and Vamanu (1995), p. 13.

Even the transportation of nuclear waste material has shown to have an effect on property values, especially in highly populated urban areas these transports have been shown to have a significant impact on property values[256]. The optimal routing strategy for nuclear waste transport is therefore also in the centre of interest of the researchers[257].

4.2.2 Transportation Accidents

A lot of disasters happen during the transportation of delivery of various goods, therefore these hazards cannot be neglected in this thesis. Management of accidents on all four main methods of transportation, train, road, ship, and aircraft are shortly reviewed in the following sub-sections.

4.2.2.1 Train Accidents

As accidents with trains are occurring quite often all around the world, research has been done in this field in order to improve overall security in the railway system.

The British rail decided to implement a Train Protection Warning System, as by that time Automatic Train Protection, a complex system that uses transmitters on the track side to be able to vary the speed of the train depending on the line conditions, did not show cost-effective in the first cost-benefit analysis[258]. It has been shown that Monte Carlo Simulation would have led to another decision, as critical values have not been taken into consideration in the cost-benefit analysis[259] .

Furthermore, the transportation of hazmat via rail is evaluated[260,261]. For hazmat transportation via rail, the optimal design of railway tank cars has been studied. A tradeoff between "increased damage resistance and greater exposure to accidents"[262] has been analyzed, as a thicker tank increases vehicle weight and leads to a higher number of hazmat shipments. An optimal tank thickness has been found but there does not exist one single optimum for all different tankers[263].

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[256] Cp. [164] Gawande and Jenkins-Smith (2001), p. 207.
[257] Cp. [21] Chen et al. (2008), p. 363ff.
[258] Cp. [71] Riddington et al. (2004), p. 606f.
[259] Cp. [71] Riddington et al. (2004), p. 612.
[260] Cp. [271] Van der Vlies and Suddle (2008), p. 119ff.
[261] Cp. [273] Verma and Verter (2007), p. 1287ff.
[262] [101] Barkan et al. (2007), p. 1266.
[263] Cp. [101] Barkan et al. (2007), p. 1266ff.

4.2.2.2 Road Accidents

The transportation of hazmat is a well discussed problem in the literature[264]. The pre-planning of transportation routes which reduces overall societal costs and minimizes population exposure is the predominant goal in all of the papers. General quantitative risk assessment based on past incidences shows the distances to which the public should be protected in case of a hazmat accident[265].

How the routing decision for hazmat can be changed when differing the routes through tunnels or diversions[266] has also been studied in the literature. The adherence of safe distances in dealing with hazmat is important for releases stemming from static sources i.e., fixed tank or transportation accidents[267].

In order to minimize the variance of the consequences and the disutility of consequences, the shortest path problem has been shown as a good approach[268,269,270,271,272,273,274]. An arc-covering model tries to find the optimal location of response teams in Eastern Canada and it has been shown that response capability can considerably be improved by relocation of the existing stations[275]. Another approach in the literature focuses on the equity of risk in the routing of hazardous material transportations[276]. A job-shop scheduling problem tries to solve the hazmat routing and scheduling decision for more than only one vehicle carrying hazmat to avoid two vehicles to be too close to each other[277].

Furthermore, hazmat transportation routing strategies can also be influenced by governmental decisions. Hence, transport organizations have to select the optimal path out of a pre-selected network from the government and significant reductions of the overall exposure risk can be achieved[278]. The same problem among a regulators' and a carriers' routing decisions has been

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264 Cp. [202] Jin et al. (1996), p. 710.
265 Cp. [118] Brown and Dunn (2007), p. 1243.
266 Cp. [82] Van Steen (1987), p. 231ff.
267 Cp. [168] Godoy et al. (2007), p. 847.
268 Cp. [32] Erkut and Ingolfsson (2000), p. 176f.
269 Cp. [75] Sherali et al. (1997), p. 237ff.
270 Cp. [26] Dadkar et al. (2008), p. 333ff.
271 Cp. [19] Chang et al. (2005), p. 383ff.
272 Cp. [225] Miaou and Chin (1991), p. 64ff.
273 Cp. [16] Carotenuto et al. (2007a), p. 1304ff.
274 Cp. [8] Batta and Chiu (1988), p. 84ff.
275 Cp. [12] Berman et al. (2007), p. 1374.
276 Cp. [169] Gopalan et al. (1990), p. 961ff.
277 Cp. [17] Carotenuto et al. (2007b), p. 1328ff.
278 Cp. [51] Kara and Verter (2004), p. 188ff.

solved for the provinces Ontario and Quebec in Canada[279]. Though, the overall costs of the intervention increases when government influences routing decisions beforehand[280].

A telegeomonitoring system, based on GIS and telecommunication systems evaluates hazmat routing strategies which minimize transportation risk as it takes into account the location of civil infrastructure[281]. "A new algebraic structure for the K-best fuzzy shortest path-finding in the valued fuzzy graph"[282] has been proposed. The same question is analyzed using a branch-and-bound algorithm, also taking meteorological conditions and population distribution into consideration[283]. How weather conditions might affect the routing of hazmat has also been evaluated[284].

Nevertheless, it has been shown that the different objectives in the hazmat models, e.g., minimizing overall risk, minimizing incident probability and minimizing total population exposed lead to very different outcomes, i.e., different optimal paths. Therefore, the objectives of the decision maker and the nature of the hazmat transported are crucial for the appropriateness of the selected optimal path[285]. Real-time routing models are also a very promising tool in the hazmat routing decision making process[286].

4.2.2.3 Ship Accidents

Safety concerns in the shipping industry are also a field of research in disaster management. The legendary sinking of the Titanic underlines the disastrous consequences of shipping accidents, in the 21st century, mournful ship accidents related to the smuggling of human beings caused thousands of deaths all around the globe.

A cost-effectiveness analysis has been conducted in order to analyze a range of policy options for improving or at least maintaining safety in one of the busiest shipping areas in the world, the North Sea. Several tactics have proven to be very promising as they increased safety and/or decreased the related costs[287].

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279 Cp. [84] Verter and Kara (2008), p. 29ff.
280 Cp. [31] Erkut and Gzara (2008), p. 2244.
281 Cp. [110] Boulmakoul (2006), p. 1514.
282 [110] Boulmakoul (2006), p. 1524.
283 Cp. [52] Karkazis and Boffey (1995), p. 201.
284 Cp. [2] Akgün et al. (2007), p.1351.
285 Cp. [149] Erkut and Verter (1998), p. 639ff.
286 Cp. [102] Beroggi (1994), p. 508.
287 Cp. [85] Walker (2000), p. 120.

Routing strategies for vessels transporting oil have also been evaluated in the literature[288]. To avoid ship collisions, there exist optimal trajectories theories, e.g., defining the minimum distances among ships[289].

4.2.2.4 Aircraft Accidents

A risk analysis of major civil aircraft accidents has been performed via an empirical study of expert judgements in order to predict future risks. It has been accepted that the average number of aircraft accidents per year will be less than the average number of accidents which occurred during 1989 and 1993, so a decrease of fatalities of 1% has been expected[290].

Measures taken to avoid terrorist attacks in aircrafts, are reviewed in Section 4.3.1.

4.2.3 Miscellaneous Accidents

In the field of miscellaneous accidents, disasters such as the collapse of domestic/non-industrial structures, explosions, and fires are subsumed[291], not already been taken into consideration in the above mentioned sections.

Several mitigation studies have been conducted such as to guarantee private dam safety in Australia. Without the appropriate design and construction and furthermore the maintenance of the small dams, their collapse can cause non-negligible human losses and raise significant costs. The sufficient capacity of the spillways is a crucial characteristic of a dam. A cost-effective regionalized flood safety design, SpillwaySafe has been introduced, minimizing the costs for private dam owners[292]. It is a tool for "conducting a state-of-the-art reservoir flood capability evaluation and/or design"[293].

In order to early detect a fire in a commercial building, the use of glass bulb sprinkler in combination with a voice system denoting live directives dominates the use of smoke detection and deluge systems in combination with voice systems[294].

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[288] Cp. [47] Iakovou (2001), p. 19ff.
[289] Cp. [226] Miele and Wang (2006), p. 19.
[290] Cp. [106] Bigün (1995), p. 599ff.
[291] Cp. [228] Moe and Pathranarakul (2005), p. 397.
[292] Cp. [68] Pisaniello and McKay (2007), p.176ff.
[293] [68] Pisaniello and McKay (2007), p.188.
[294] Cp. [24] Chu and Sun (2007), p. 1ff.

4.3 Terrorism Forms

In addition to the two above mentioned types of disasters, namely natural and technological disasters, we found it important to extend the common classification to terrorism forms. As in the last decade, the number of terrorist attacks increased considerably, efficient disaster management also becomes vital for these hazards. The major threat in the field of terrorism seems to be an attack on critical infrastructure such as on nuclear reactors and water reservoirs, a bioterrorist attack, or the spreading of radioactive material[295]. Compared to biological epidemics which seem to spread analogously to mathematical rules, "terrorists are individuals that can behave rationally trying to maximize the damage caused"[296].

Therefore, an analysis of the risk of terrorism to critical infrastructure is very important and the increasing interdependencies and intradependencies need to be included into the decision making process[297]. Critical information infrastructure and its vulnerability to eventual threats also needs to be evaluated[298].

Another approach focuses on how to protect critical infrastructure through an optimal allocation of protective facilities[299]. "The emerging dominance of software in the entire lifecycle of our information systems, coupled with the risk and uncertainty associated with its development and maintenance, increases the vulnerability of information systems"[300]. Value models might also be applied to investigate the usefulness of anti-terrorism alternatives and to define potential terrorist priorities[301].

A division of the literature into terrorism and bioterrorism has been found useful for this purpose.

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[295] Cp. [11] Berman and Gavious (2007), p. 1113.
[296] [11] Berman and Gavious (2007), p. 1114.
[297] Cp. [180] Haimes and Longstaff (2002), p. 439.
[298] Cp. [170] Gorman et al. (2004), p. 48ff.
[299] Cp. [251] Scaparra and Church (2008), p. 1905ff.
[300] [180] Haimes and Longstaff (2002), p. 442.
[301] Cp. [207] Keeney (2007), p. 585.

4.3.1 General Terrorism

"The man made disaster risk has increased due to a rise in possibility of terrorist attacks"[302].

The terrorist attack on the World Trade Centre in New York of September 11th, 2001, suddenly raised public awareness with regard to this field of disaster management. In order to deal with such a situation, cooperation and communication among various agencies is required and emergency managers face a complex problem which has been shown in an analysis of management of terror incidents in Jerusalem. Fire brigades and rescue services are an integral part in the disaster response process, therefore their actions need to be accurately and effectively planned for the purpose of timely interventions[303]. Terrorist population dynamic models are a tool to describe the evolution of terrorist systems[304].

Urban vulnerability analysis based on past terrorist incidences is important in order to assess the risk of future attacks. Here, it has been shown that an overall strategy of resource allocation is not useful, as vulnerability strongly depends on the location of the potential disaster site[305].

How counter-terrorist operations might influence the recruitment to terrorist organizations is also studied in the literature. One can divide the strategies into water strategies, i.e., that do not provoke recruitment of new terrorists, and fire strategies, i.e., that do provoke recruitment of terrorists[306]. The optimal deployment of physical defensive resources and decisions about the issuance of private and public warnings is sensitive to the quality of governments' information about the terrorist attack[307].

A simulation of the Georgia Emergency Management Agency, GemaSim has indicated that a decreasing skill level of the agents working in the emergency department as well as phone and network problems might decrease the overall performance of an emergency management agency in case of a terrorist attack[308]. Simulation is also used so as to prepare for a range of security risks in large sport events such as Olympic Games[309].

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[302] [198] Jain and McLean (2005), p. 904.
[303] Cp. [237] Perliger et al. (2005), p. 79.
[304] Cp. [204] Kaminskiy and Ayyub (2006), p. 747ff.
[305] Cp. [240] Piegorsch et al. (2007), p. 1411ff.
[306] Cp. [121] Caulkins et al. (2008), p. 1874ff.
[307] Cp. [242] Pinker (2007), p. 879.
[308] Cp. [217] Loper and Presnell (2005), p. 902.
[309] Cp. [203] Johnson (2008), p. 302ff.

In order to test or develop new emergency management plans for a series of terrorist threats in Laporte County, a simulation environment has been created. This should help evaluate the readiness and capacity of the county's private health system as well as its integration into the general emergency response system[310]. To protect cities from terrorists attempting to place nuclear weapon in the city centre, a spatial queueing system has been developed[311].

Game theory has been used to describe anti-terror measures taken by the government, dealing with the installation of anti-terror facilities in the USA. It is a leader-follower game where both the State as the leader and the terrorists as the followers try to either minimize or maximize disutility for the metropolitan area[312]. The same approach has been used to solve the allocation problem for defensive resources and to model the strategic behaviour of the attacker[313]. Game theory is also used to find the optimal balance between controlling the growth of terrorist cells and the overall costs of the control mechanisms[314], and to show that for a defender it is not only important to find potential targets of the attacker but to take the attacker's response to investment in defensive structures into account[315].

Moreover, hypergame theory has been applied in the terrorism context as it "provides an approach to pre-planning, situational discovery and model updating"[316].

In the area of response activities, it is crucial that experienced trauma teams are transported in the disaster zone and that seriously injured people are rapidly transported to higher level medical facilities, as has been shown after the terrorist bombing in Taba in October 2004[317].

In the aftermath of 9/11 airport passenger security systems have been re-evaluated. A DES provided a good analytical support for airport security operations focusing on resource requirements, as well as customer experiences and costs[318]. Furthermore, the optimal deployment of baggage screening security devices has been investigated, based on different performance criteria, uncovered baggage segments, uncovered flight segments, and uncovered

[310] Cp. [114] Brady (2003), p. 1863ff.
[311] Cp. [97] Atkinson and Wein (2008), p. 247ff.
[312] Cp. [11] Berman and Gavious (2007), p. 1113.
[313] Cp. [105] Bier (2007), p. 607ff.
[314] Cp. [154] Feichtinger and Novak (2008), p. 1f.
[315] Cp. [282] Zhuang and Bier (2007), p. 989f.
[316] [272] Vane III (2005), p. 972.
[317] Cp. [206] Karp et al. (2007), p. 104.
[318] Cp. [67] Pendergraft et al. (2004), p. 874ff.

passenger segments[319]. An evaluation of security screening of airline passengers has found that an improvement of overall baseline screening of all passengers might be more beneficial than an increase in terrorist detection probability or a marginal increase of secondary screening probability[320].

Another approach in the literature focuses on a single-server queue with disasters, where a negative customer removes all the customers in the system[321,322,323,324]. The correlation of positive and negative customers is assumed here, this might be for example a computer virus in an email system, and a higher number of emails are supposed to lead to a higher number of infected mails[325]. Queueing networks might also be used to analyze migration processes with catastrophes and virus infections not only in email systems but generally in computer systems[326,327]. Cyber-terrorist attacks are a real threat for critical infrastructure, as due to the internet and the universal access to computers national boundaries have been eliminated[328].

A study, not directly related to information technology (IT) -Terrorism but still dealing with the problem of the preparedness of computer networks when a disaster occurs, investigates a new way of coping with the problem besides the commonly used expected value analysis. The new approach focuses on stochastic dominance techniques which facilitate to compare different contingency plans due to the estimates of the total loss distribution[329].

4.3.2 Bioterrorism

Bioterrorism is a method of terrorism not performed with weapons in the narrower sense but with microorganisms, so called biological agents, as they are anthrax, botulism, plague, smallpox, and other viruses and bacteria[330]. Risk analysis in this field is especially difficult as until now only a relatively small number of cases have occurred, there is a likely low rate of

[319] Cp. [48] Jacobson et al. (2005), p. 341f.
[320] Cp. [221] Martonosi and Barnett (2006), p. 551.
[321] Cp. [254] Shin (2004), p. 364ff.
[322] Cp. [95] Artajelo (2000), p. 241.
[323] Cp. [94] Artajelo and Gómez-Corral (1999), p.79.
[324] Cp. [96] Atencia and Moreno (2004), p. 1537.
[325] Cp. [254] Shin (2004), p. 364ff.
[326] Cp. [123] Chao (1995), p. 75.
[327] Cp. [95] Artajelo (2000), p. 241.
[328] Cp. [180] Haimes and Longstaff (2002), p. 442.
[329] Cp. [244] Post and Diltz (1986), p. 363.
[330] Cp. [289] CDC [access on June 1st, 2008].

future attacks, and there is only limited information about the intent and capabilities of terrorist groups planning a bioterrorist attack[331].
Although there are similar approaches to deal with these attacks, several differences between anthrax and smallpox attacks need to be pointed out. Anthrax can be treated with antibiotics and is not contagious whereas smallpox needs to be prevented via vaccination and is highly contagious[332].

Bioterrorist attacks are a phenomenon of the last decade and several anthrax attacks via the United States (US) postal system[333] have underlined the vulnerability of the community for this genre of terrorism. Hence the potential threat is very high and the most hazardous substances are anthrax, smallpox, yersinia pestis, vibrio choleram salmonella typhi and clostridium botulinum[334]. Some of these agents are more likely to be chosen for bioterrorist attacks as they are highly infectious and can cause massive civilian causalities and high mortality[335].

Anthrax spores, released over a suburban area, might expose about 100,000 people of whom 30,000 are dying, and causes economic damages of over USD 25 billion[336]. The dispersion of anthrax spores in the ventilation system of a 50 stores building has been simulated via computer simulation. It has been found that “differentials in spore size and concentration for each floor will influence the likelihood of exposure occurring on individual floors”[337]. Furthermore, the effective detection of the release of anthrax and early intervention can additionally reduce the dispersion of the bioterrorism agent in the building[338].

Mass decontaminations are conducted in case of a chemical, nuclear or radiological incident, a simulation with 20,000 affected people has lead to a decontamination time of approximately 18 hours, a slight change in the arrival time of the decontamination tents, the number of fire fighters and non-ambulant patients might effect the initial decontamination time[339].

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331 Cp. [283] Zilinskas et al. (2004), p. 902.
332 Cp. [86] Whitworth (2006), p. 562f.
333 Cp. [98] Babbs and O’Connor (2003), p. 118ff.
334 Cp. [156] Foxell (1997), p. 104.
335 Cp. [70] Reshetin and Regens (2003), p. 1135.
336 Cp. [70] Reshetin and Regens (2003), p. 1136.
337 [70] Reshetin and Regens (2003), p. 1144.
338 Cp. [70] Reshetin and Regens (2003), p. 1144.
339 Cp. [3] Albores and Shaw (2005), p. 890.

The design of point of dispensing after a bioterrorist attack such as an anthrax attack has become more and more important during the last years. This infrastructure is used after a large-scale attack in order to be able to treat a high amount of people affected[340,341,342]. The dispensing process encompasses assembly, triage, orientation, registration, screening, service, education, and discharge of the affected population[343]. As operational guidelines for such a clinic, a separate entrance for staff, the careful regulation of residents arrival at the clinic, and a clear workflow have been named[344]. Furthermore, it is crucial to manage clinic traffic and parking next to the dispensing centre to avoid an additional bottleneck in the system due to congested roads and parking areas[345].

In order to prepare a community for a bioterrorist attack, antibiotic inventories can either be stored at national, regional or local level. So called push-packs, inventory stored at the national level, contain antibiotics, antidotes, and other medical supplies, at the regional level vendor-managed inventories are used[346]. Local inventory encompasses both local storage of antibiotic inventory and dispensing capacity[347]. These inventories differ only in the time of availability, i.e., local inventories are immediately available and push-packs are sent to the disaster site about 12-48 hours later. In the US it has been found that at the local level it is always more effective to increase dispensing capacity than to increase local antibiotic inventory. Overall, it is more effective to rely on inventories at the national or regional level than to increase local inventory level[348].

The quick detection of the bioterrorist attack is once more underlined, although improved surveillance systems only decrease the number of deaths when there is enough capacity for dispensing prophylactic antibiotics at the local level[349]. Furthermore, the effectiveness of local inventory stockpiling strongly depends on the annual probability of a bioterrorist attack[350]. The staff requirements in a dispensing centre have also been studied in the literature, the prevalence of the attack has a strong influence on the number of staff required[351].

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340 Cp. [56] Lee et. al (2006), p. 27.
341 Cp. [1] Aaby et al. (2006), p. 569ff.
342 Cp. [86] Whitworth (2006), p. 562ff.
343 Cp. [56] Lee et. al. (2006), p. 28.
344 Cp. [1] Aaby et al. (2006), p. 574ff.
345 Cp. [86] Whitworth (2006), p. 566.
346 Cp. [90] Zaric et al. (2008), p. 1ff.
347 Cp. [90] Zaric et al. (2008), p. 12.
348 Cp. [90] Zaric el al. (2008), p. 14.
349 Cp. Ibidem.
350 Cp. [90] Zaric et al. (2008), p. 15.
351 Cp. [45] Hupert et al. (2002), p. 17ff.

Optimization is used to analyze the impact of various key parameters affecting the number of deaths after a bioterrorist attack as they are prophylactic efficacy, treatment efficacy, intervention delay, the time to distribute antibiotics, and the number of people in waiting queues[352].

Furthermore the cost-effectiveness of two mitigation strategies, universal vaccination and an emergency surveillance and response system, i.e., to detect the attack more rapidly and administer post-exposure prophylaxis, has been considered[353]. The emergency surveillance system shows considerably cost-effective in case of a highly probable large-scale attack. Anyhow, the response component influenced the result more strongly than the surveillance component. Vaccination showed less effective as a very low rate of anthrax immunization was subsumed[354]. The effectiveness of vaccination strategies in case of a bioterrorist attack with smallpox has also been considered[355].

For a smallpox attack, besides vaccination, social mixing control, i.e., trying to reduce daily contacts of a person to a minimum has been taken into consideration[356]. Mass vaccination, quarantine, the shutdown of general meeting sites such as public transport, the closure of daily meeting sites such as schools, and the request to people to stay home were evaluated. In this hypothetical scenario it has been found that a combination of vaccination and social mixing control measures is the most effective intervention[357]. A simulation of a smallpox attack in San Antonio underlines the usefulness of a combination of several strategies, even while employing several of the strategies at less than optimal performance levels, the epidemic could be averted[358].

A Markov model compares the cost-effectiveness of pre-anthrax-attack vaccination, post-attack antibiotic therapy combined with vaccination of exposed persons, and post-attack antibiotic treatment without vaccination of exposed persons, of US postal workers[359]. It has been found that the second of the above mentioned strategies was the cost-effective strategy, an earlier detection more and more reduces the effect of post-attack vaccination and enhances

352 Cp. [25] Craft et al. (2005), p. 692.
353 Cp. [13] Braithwaite et al. (2006), p. 182ff.
354 Cp. [13] Braithwaite et al. (2006), p. 191.
355 Cp. [54] Kress (2006), p. 22.
356 Cp. [55] Kress (2005), p. 277ff.
357 Cp. [55] Kress (2005), p. 284.
358 Cp. [61] Miller et al. (2006), p. 587.
359 Cp. [73] Schmitt et al. (2007), p. 655ff.

the effectiveness of antibiotic therapy as a single treatment[360]. For a large scale attack in the US, vaccination and antibiotic treatment are the most effective post-attack strategies, the effectiveness of pre-attack strategies depends on the probability of the attack and the number of people exposed[361].

Once again, the importance of timely detection and response after an attack has been underlined by a statistical model evaluating the effectiveness of post-exposure prophylaxis[362]. The optimal duration of antibiotic prophylaxis after an anthrax attack is 60 days (for a high amount of spores inhaled) to four months (if a lower amount of spores is inhaled)[363].
For clinicians' decisions related to diagnosis, detection, and management of the bioterrorist attack, prevention of a further spread of the disease and the communication with public health officials are the main tasks while responding to bioterrorist events. Public health officials are rather focused on overall surveillance, the investigation and control of the outbreak of the disease and the communication with clinicians, other public health officials as well as the public[364].

It has further been found that existing surveillance systems for the early detection of bioterrorist attacks are not sufficiently able to characterize timeliness, sensitivity or specificity of the illnesses[365].

4.4 Disaster Activities

A vast amount of literature does not focus on a specific disaster type but is applicable to various or all disaster types. These research directions are looked at on the following pages.

Great incidences are the source of the majority of disaster-related costs, but often a lack of data renders it difficult to determine the distribution of incident size which reflects these disasters and therefore making incident risk assessment difficult. After the application of several models on real data it has been found that the log-normal function underestimates the probability of larger disastrous events. Accumulated losses are best assessed by the Pareto 1

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[360] Cp. [73] Schmitt et al. (2007), p. 659.
[361] Cp. [34] Fowler et al. (2005), p. 607f.
[362] Cp. [4] Baccam and Boechler (2007), p. 29f.
[363] Cp. [117] Brookmeyer et al. (2003), p. 10129ff.
[364] Cp. [116] Bravata et al. (2004b), p. 192.
[365] Cp. [115] Bravata et al. (2004a), p. 910ff.

distribution. Further results "justify the assumption of a power law distribution of variability for assessment of planning period losses from limited available data record"[366]. Moreover due to the Bayesian approach incident risk from available data can be assessed, especially useful for disaster risk assessment in developing countries or site-specific incidents[367].

"[…] different aspects of the risk of extreme events"[368] can also be looked at via decision-tree analysis, sequential decision making[369]. Here, the risk of extreme events[370] as well as the risk of rare events[371] was considered via multi-objective decision trees. Efficient data and information sharing is one of the main pillars in effective disaster management[372].

4.4.1 Pre-Disaster Activities

As cooperation[373] is the predominant characteristic of successful disaster management, multi-agency counselling might be a successful support after an extreme event. Methods of soft systems methodology are applied dealing with the on-going exploration of the perceptions of the participants. It has been shown that this collaboration of the representatives was very fruitful, and a considerable amount of plans have been produced in a very short period of time[374]. This aspect is also taken into consideration when trying to elicit, gather and summarize knowledge of experts all over the globe. A specific algorithm was created where experts can contribute their knowledge, discuss on each others' ideas and decide on a consensus[375].

Further pillars of effective disaster management are, besides cooperation, communication[376], and an effective distribution of tasks among the involved parties[377]. The way how to evaluate a disaster recovery plan with OR/MS methods has also been described in the literature[378].

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366 [148] Englehardt (2002), p. 380.
367 Cp. [148] Englehardt (2002), p. 380.
368 [160] Frohwein et al. (1999), p. 69.
369 Cp. [160] Frohwein et al. (1999), p. 69.
370 Cp. [162]Frohwein and Lambert (2000), p.113ff.
371 Cp. [161] Frohwein et al. (2000), p. 125ff.
372 Cp. [133] Dantas and Seville (2006), p. 38ff.
373 Cp. [223] Mendonça et al. (2006), p. 523ff.
374 Cp. [175] Gregory and Midgley (2000), p. 278ff.
375 Cp. [224] Mendonça et al. (2000), p.193f.
376 Cp. [190] Hoogendorn et al. (2008), p. 1422ff.
377 Cp. [279] Wybo and Kowalski (1998), p. 132ff.
378 Cp. [119] Bryson et al. (2002), p. 679ff.

As for rare events the number of observed events is usually too small to derive accurate estimates, precursor analysis is used to close this gap. This analysis helps to investigate dependencies in safety systems and underlines whether one system failure favours another failure in another system. That way, accident frequencies can be estimated consistently[379].

Where to optimally locate disaster recovery centres in Florida county has been evaluated in the literature[380]. Covering location problems are furthermore used in order to efficiently locate fire trucks and ambulances in a geographic area[381,382]. The objective of these models is the detection of the minimum number of units required as well as the respective location of response vehicles in order to be able to meet the demand at the nodes of the model. Demand is considered as being covered in case that there is at least one unit of a truck or ambulance available within a pre-defined distance. Using a maximum covering location model, it has been found that although the number of available units has been limited, a substantial coverage such as over 94% of the demand could be achieved[383].

Location problems, with the extension of units that might already service another customer (i.e., unreliable facilities), such as ambulances, are solved with p-median and p-centre problems. Demand has to be covered not by the closest unreliable but by the second closest unit. The objective of the former problem is to minimize the sum of weighted distances between the demand points and the closest units, the objective of the latter is to minimize the maximal weighted distance between demand points and units. The (p,q) problem deals with a situation in which out of p units q become unreliable or busy and the remaining units still are put at the optimal location[384].

The p-median problem is also used to deal with the unreliable planar location problem, in which it is not units but entire facilities such as fire stations becoming unreliable due to capacity or resource constraints. The question arising is now where to implement new facilities in this unreliable framework. It has been found that the initial location of new facilities was the main determinant for the quality of the final outcome of the heuristics, and

379 Cp. [280] Yi and Bier (1998), p. 258.
380 Cp. [135] Dekle et al. (2005), p. 133ff.
381 Cp. [247] ReVelle and Snyder (1995), p. 261ff.
382 Cp. [9] Batta and Mannur (1990), p. 16ff.
383 Cp. Ibidem.
384 Cp. [144] Drezner (1987), p. 509ff.

the heuristics have proven efficient[385]. As the problem of unreliable facilities rather occurs during normal accidents, this approach is not further considered in the taxonomy of the next section.

4.4.2 Post-Disaster Activities

For efficient response after large disasters it is often required to estimate population size in the affected region. This can either be conducted through the Quadrat method or the T-Square method. A comparison with the census has shown that the T-Square method yields a better estimate of the population although it is more difficult to implement, whereas both methods showed useful for estimation of the age distribution of the population[386].

Another approach in the literature addresses the effect of disasters on population growth and development. Normally, population grows "according to some continuous-time Markov chain (e.g., a compound or non-homogeneous Poisson process, a general immigration-birth process, or a simple immigration-birth-death process)"[387]. Total catastrophes are used in order to model the effects of natural disasters reducing the population size immediately to zero. This consideration is also used in queueing models[388]. Queueing networks are not only applied in disasters related to IT terrorism but might also be used to analyze migration processes due to catastrophes[389].

The occurrence of disaster poses also a broad range of logistical problems, for example to "design the transportation of first aid material, food, equipment, and rescue personnel from supply points to a large number of destination nodes geographically scattered over the disaster region"[390] as well as the evacuation and transportation of people affected[391]. Generally speaking, it is the task of efficient disaster management to move different commodities via different modes of transportation from the respective origins to one or more destinations affected by a disaster over a transportation network in a timely, effective, and efficient way[392].

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[385] Cp. [216] Lee (2001), p. 329ff.
[386] Cp. [172] Grais et al. (2006), p.364.
[387] [146] Economou and Fakinos (2003), p. 625.
[388] Cp. [146] Economou and Fakinos (2003), p. 628.
[389] Cp. [123] Chao (1995), p. 75.
[390] [7] Barbarasoğlu et al. (2002), p. 118.
[391] Cp. [7] Barbarasoğlu et al. (2002), p. 118.
[392] Cp. [41] Haghani and Oh (1996), p. 232.

The problem formulated in the model focuses on the crew assignment, routing, and transportation issues of helicopter logistics and the interaction and coordination of the tactical and operational decisions taken are considered. It has been shown that the helicopter selection is easier in case that there is a sufficient number of pilots available and the tightness of capacity can be measured by the fleet composition done by the tactical decision makers[393]. The determination of a detailed routing and scheduling of all available transportation modes as well as load plans and delivery schedules is conducted by a multi-commodity multi-modal network flow problem, serving as a decision support tool for emergency managers[394].

The question of emergency evacuation is very often analyzed in the disaster management literature. In order to design such emergency evacuation networks, queueing networks and graph theory are used to model this kind of problem. In an emergency situation, finite sized corridors and staircases can only pass a very limited number of people at the same time and might be considered as bottlenecks in the evacuation process of buildings, as bridges, and two lane highways are considered the same in a regional context. As it can be straightforward expected, the width of corridors plays a predominant role in the evacuation process, although the model is even able to quantitatively calculate the effect of changes in width on the overall evacuation process. The throughput as well as the egress time have improved due to the resizing of the corridors[395].

An even challenging approach for evacuation management is the simultaneous planning of emergency response resources to be dispatched to the disaster site and the evacuation of people exposed away from the affected area[396]. For example, a simulation tool evaluated several different evacuation strategies in Knox County, Tennessee, and found that one-destination dynamic routing was the most efficient scenario in terms of evacuation time and number of people evacuated[397].

The wayfinding problem in emergency evacuations deals with the decision of each person in a building which needs to be evacuated. As people normally lack sufficient information about the building, they select their paths randomly. The problem has been implemented in the Hampton Court and the following models of route choice have been considered: walk

[393] Cp. [7] Barbarasoğlu et al. (2002), p. 119ff.
[394] Cp. [41] Haghani and Oh (1996), p. 232.
[395] Cp. [5] Bakuli and MacGregor Smith (1996), p. 543ff.
[396] Cp. [22] Chiu and Zheng (2007), p. 710ff.
[397] Cp. [43] Han et al. (2006), p. 508f.

correctly, always turn left, random choice, follow planned path, directional choice, shortest path and frequently used path. The decision of an individual may be completely different from the choice taken in a group, as groups tend to follow authoritative persons. Using the simulation programme EVACSIM, random choice has shown the worst performance, memorized random choice shows the best outcome in terms of time needed to exit the Hampton Court building[398].

Evacuation models can also be developed using lexicographical optimization[399].
The simulation of pedestrian crowds further enhances the understanding of crowd behaviour in emergency situations and underlines the necessity of sufficiently large egress routes[400]. Disaster evacuation plans can also be evaluated through dynamic traffic assignment models[401] or simulations[402].

A simulation-based urban evacuation analysis studied optimal evacuation plans for an urban area. Different road types and population densities have been evaluated and different evacuation strategies have been defined. It has been found that for scenarios with low population density, simultaneous evacuation strategies lead to the lowest evacuation times in grid road networks, whereas in denser populated areas, staged evacuation strategies are preferable. The evacuation time in ring road networks did not show any significant difference with regard to variations in the population density. Using simulation to model real world road networks, there is no difference in case of low population density but staged evacuation plans proved considerably more effective at higher levels of population density[403].

For contingency planning for emergency evacuations a spatial DSS linking simulation techniques with the positive features of a GIS has been developed. Emergency planners are now able to use the interactive evacuation simulator to make plans for different contingencies and to experiment with different evacuation plans[404]. Still this Configurable Emergency Management and Planning System has some weaknesses, namely that some realistic traffic

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398 Cp. [58] Løvås (1998), p. 371ff.
399 Cp. [183] Hamacher and Tufekci (1987), p. 487ff.
400 Cp. [188] Helbing et al. (2005), p. 22.
401 Cp. [131] Daganzo (1995), p. 92.
402 Cp. [23] Chow and Ng (2008), p. 844ff.
403 Cp. [20] Chen and Zhan (2008), p. 25ff.
404 Cp. [134] DeSilva and Eglese (2000), p. 423.

properties are not yet included in the system and some technical restrictions still need to be overcome[405].

Moreover, the problem of a combined evacuation and commodity dispatching model has been discussed in the literature[406]. Robotic systems have shown to be able to further enhance disaster response activities[407].

Furthermore, especially after large-scale natural disasters a quick restoration of electrical power network is crucial. Therefore, a model has been implemented in order to optimally assign crews and depots in the affected area[408].

[405] Cp. [239] Pidd et al. (1996), p. 418.
[406] Cp. [88] Yi and Kumar (2007), p. 660ff.
[407] Cp. [108] Blitch (1996), p. 109ff.
[408] Cp. [60] Mann et al. (1996), p. 367ff.

5 TAXONOMY

The previous sections provided an insight in the different focuses of disaster management related literature. In the taxonomy, a selection of papers has been examined in detail to underline different outcomes and to emphasize particular results and research directions. Articles dealing with disaster management but not describing interventions in a narrower sense, and not exclusively dealing with the abovementioned parameters, do not appear in the taxonomy but were shortly reviewed in the previous section.

In the past years, the planning of emergency management systems[409] became more and more relevant. Here, we focus exclusively on literature dealing with the management of exceptional events, exceeding the dimension of "normal" or "ordinary" catastrophes and incidences. "Catastrophic risk is typified by its low frequency and high severity"[410] (low probability, high-consequence)[411,412]. In this respect, the burning of a house is considered as being a normal catastrophe, whereas wild fires or the burning of buildings because of an explosion of a chemical plant in the surrounding is considered as a disastrous event.

There exists a vast literature dealing with vehicle routing problems[413] of all kinds, here only disaster related vehicle routing problems[414] of ambulances[415] or the transport of hazardous materials has been included. Facility location problems[416,417] have been reduced to the ones dealing with the location of response facilities, only with regard to disastrous events. Maximal expected coverage relocation problems focusing only on ambulance relocation under normal situations have been excluded[418]. An exception is the covering-location model developed by Batta and Mannur (1990) [9], as it explicitly focuses on emergency situations requiring multiple response units[419].

[409] Cp. [173] Green and Kolesar (2004), p. 1002ff.
[410] [158] Freeman and Pflug (2003), p. 602.
[411] Cp. [160] Frohwein et al. (1999), p. 69.
[412] Cp. [148] Englehardt (2002), p. 369.
[413] Cp. [193] Iannoni et al. (2008), p. 207ff.
[414] Cp. [89] Yi and Özdamar (2007), p. 1178f.
[415] Cp. [144] Drezner (1987), p. 509ff.
[416] Cp. Ibidem.
[417] Cp. [139] Doerner et al. (2005), p.325ff.
[418] Cp. [165] Gendreau et al. (2006), p. 22ff.
[419] Cp. [9] Batta and Mannur (1990), p. 16ff.

Pure maintenance problems such as preventive railway maintenance scheduling[420] are also excluded from the taxonomy.

Water resource management often deals with water shortages, but the ongoing threat of severe droughts is hardly investigated, therefore these general water resource management[421] papers are not included in the taxonomy.

All measures taken to prevent illegal and intentional oil dumping into the sea[422] have been excluded, as again the disastrous character is missing. The reliability of machines[423,424] also belongs to this category, thus this is not further considered in the taxonomy.

All kinds of immigration-emigration[425, 426,427] models are excluded from further analysis in the taxonomy as they do not focus on a specific intervention. Moreover, several papers relating to the queueing theory such as batch Markov arrival processes and Markovian arrival processes are excluded from the taxonomy as they are not intervention-related[428]. Solely risk evaluation tools without focusing on specific interventions[429, 430] are also not included in the taxonomy.

Pure descriptions of disaster management tools such as its architecture or system components without any outcomes (e.g. the description of simulation tools[431], evacuation models[432], wildfire prevention[433,434], and risk prediction[435] systems) are not included in the taxonomy.

The organisation of Emergency Management Agencies in general is a very important field of research in the disaster management literature[436]. The information processing inside these agencies is excluded from the taxonomy, as this thesis is intervention-oriented and is not

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420 Cp. [120] Budai et al. (2006), p. 1035ff.
421 Cp. [218] Maqsood et al. (2005), p. 208ff.
422 Cp. [155] Florens and Foucher (1999), p. 81ff.
423 Cp. [210] Kim and Dshalalow (2002), p. 1235ff.
424 Cp. [160] Frohwein et al. (1999), p. 69ff.
425 Cp. [214] Kyriakidis (2004), p. 198ff.
426 Cp. [146] Economou and Fakinos (2003), p. 625ff.
427 Cp. [145] Economou (2003), p. 522ff.
428 Cp. [254] Shin (2004), p. 364ff.
429 Cp. [166] Georgoudas et al. (2007), p. 124ff.
430 Cp. [246] Remondo et al. (2008), p. 496ff.
431 Cp. [259] Stähly (1989), p. 231.
432 Cp. [270] Tufekci (1995), p. 39ff.
433 Cp. [178] Guarniéri and Wybo (1995), p. 3ff.
434 Cp. [112] Boychuk et al. (2007), p. 9ff.
435 Cp. [92] Alonso-Betanzos et al. (2003), p. 545ff.
436 Cp. [217] Loper and Presnell (2005), p. 895ff.

focusing on the quality or improvement of information processing inside organizations in case of a disastrous event. Problem structuring methods are also excluded from this taxonomy, see Mingers and Rosenhead (2004) [227] for further discussion. All models dealing with the relocation of governmental agencies are also beyond the scope and therefore excluded from the taxonomy[437].

Furthermore, all kinds of state of the art descriptions of emergency management systems of different countries have been excluded, if they only focus on the structure of the systems and not on actions or activities conducted. An example is the emergency management in Korea[438]. The sole description and examination of past disasters such as the Kobe earthquake in 1995[439], the terrorist attacks in Taba[440] , the behaviour of public organizations after the Hanshin-Awaji Earthquake in 1995[441], and the urban contingency planning in Turkey[442] are also excluded from the taxonomy, still such evaluations are useful in order to derive important conclusions for future threats and to be aware of urban earthquake vulnerability.

Some approaches of the military logistics field might also be applicable to disaster relief situations but are not included in the taxonomy[443]. As this thesis focuses on the assignment of interventions against natural and technological disasters and terrorist attacks it is not intended to relate to any warfare activities.

The hypergame theory used for the planning for terrorist attacks is not included as it does not focus on the intervention itself[444]. Population surveys with regard to disastrous events and the populations' perception are also not included in the taxonomy.

In the taxonomy, features such as the level of disaster management, the model type, information about the general model, interventions, disaster type, economic analysis, general results and policy implications are considered. Figure 5 gives an overview of the dimensions, a detailed description of each of these dimensions can be found in the following sections.

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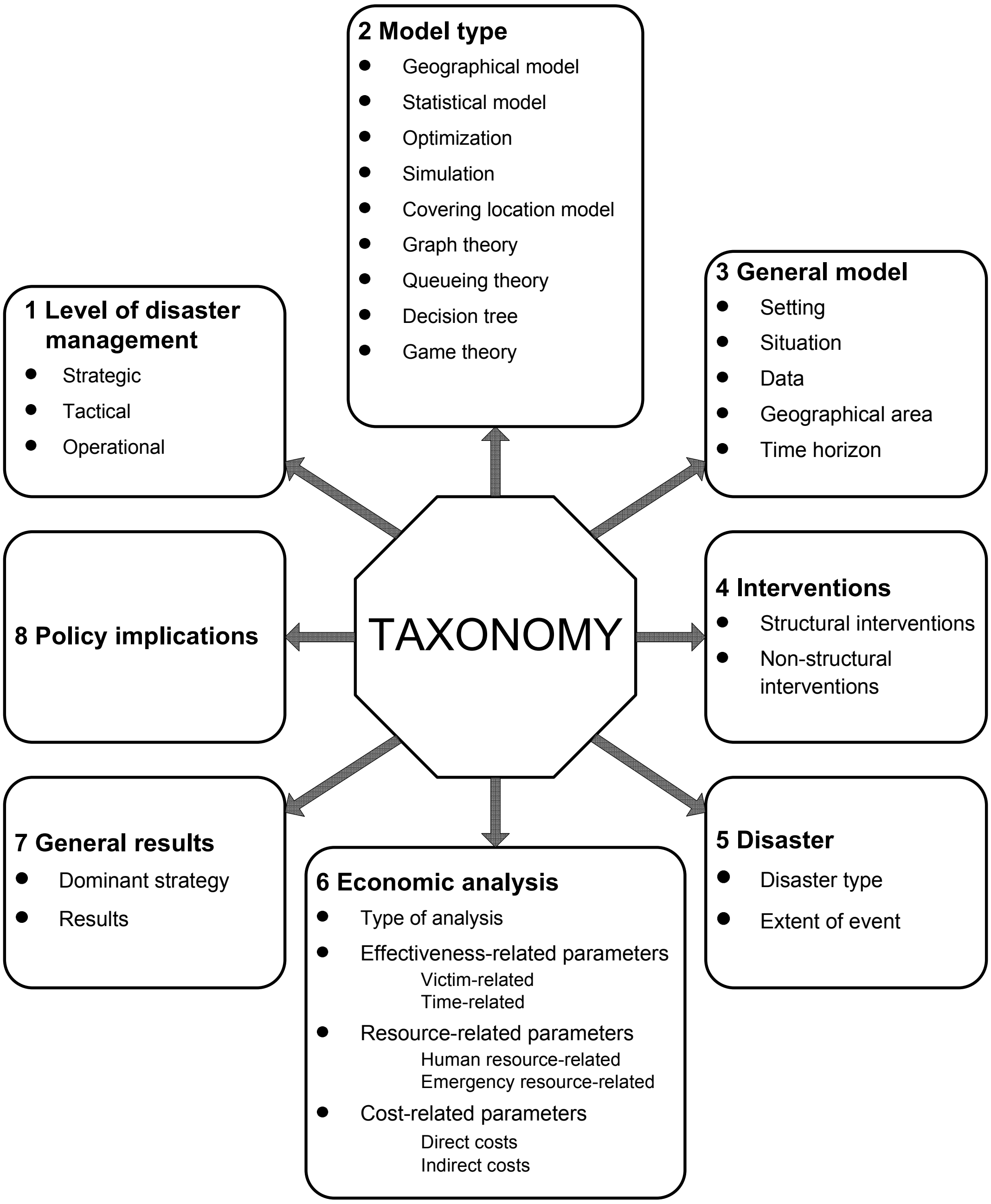
437 Cp. [263] Takamura and Tone (2003), p. 85ff.
438 Cp. [209] Kim and Lee (1998), p. 189ff.
439 Cp. [122] Chang and Nojima (2001), p. 475ff.
440 Cp. [206] Karp (2007), p. 104ff.
441 Cp. [186] Hashimoto (2000), p. 15ff.
442 Cp. [99] Balamir (2002), p. 39ff.
443 Cp. [260] Swartz and Johnson (2004), p. 773ff.
444 Cp. [272] Vane III (2005), p. 972ff.

Figure 5: Dimensions of disaster management taxonomy



Source: Own illustration

To keep the tables of the taxonomy clearly arranged, sub-categories are introduced. If a sub-category is named non-specific, it might be applied in different situations, in case it is specific, it is reserved for a specific situation. Within these sub-categories, the individual rows are ranked related to their stage in the disaster management process such mitigation, preparedness, response, or recovery.

5.1 Level of Disaster Management

In general management literature, the division of planning horizons into the strategic, tactical, and operational level is very common[445,446,447]. Strategic planning happens on a long-term scale, these goals are vague and globally formulated and it is not possible to directly transform them into operational activities[448]. The planning horizon for strategic plans is 5-10 years[449]. Tactical planning is intermediate-term focused and decisions taken at the upper level build the framework for decision making. Strong interdependencies among various functional areas have to be taken into consideration during the decision finding process[450]. Planning at the operational level encompasses sectoral short-term decision making and concrete operations guidelines are given[451]; the planning horizon is one year[452].

Besides the time-horizon, further characteristics of the three levels are the level of differentiation, level of detailedness, preciseness of information used, and structural deficiencies[453]. In a disaster management context, the three levels consider the following problem sets. The strategic decision level encompasses the pre-positioning of human and emergency resources to assure response in a timely manner. This includes the determination of storage location as well as the quantity and type of the stockpiled resources. Decisions taken at the strategic level entail constraints and boundaries for the lower decision levels. At the tactical level the resources for a specific disaster are prescribed, as for example what type and quantity of resources need to be dispatched. The lowest level, the operational level, deals with the effective insertion of the resources[454].

As can be seen in Table 3, most papers are considering mitigation or response actions, there is a high number of papers considering strategic mitigation or strategic response problems. Generally speaking, there is not a lot of research undertaken in the recovery-related section, this might be partially caused by the fact that these interventions are more expensive than actions taken in any other area.

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[445] Cp. [285] Heinen (1991), p. 64ff.
[446] Cp. [287] Schweitzer (2001), p. 34ff.
[447] Cp. [288] Von Nitsch (1998), p. 133ff.
[448] Cp. [285] Heinen (1991), p. 64f.
[449] Cp. [288] Von Nitsch (1998), p. 133.
[450] Cp. [285] Heinen (1991), p. 66.
[451] Cp. [285] Ibidem.
[452] Cp. [288] Von Nitsch (1998), p. 134.
[453] Cp. [287] Schweitzer (2001), p. 34f.
[454] Cp. [78] Srinivasa and Wilhelm (1997), p. 555.

Baccam and Boechler (2007) [4], Fowler et al. (2005) [34] and Schmitt et al. (2007) [73] consider response strategy in terms of medication and vaccination, but as pre-attack vaccination is also one strategy considered, the papers are classified as both dealing with preparedness and response strategies[455,456]. Barbarasoğlu et al. (2002) [7] encompasses both the tactical and the operational level as models on both levels are formulated and their interaction is studied[457].

Brimberg et al. (1995) [14] considers both the strategic aspect of the problem as well as the operational problem[458], while the model of Brown and Vassiliou (1993) [15] encompasses both the tactical and the operational level[459]. In Dimopoulou and Giannikos (2004) [27], response at the strategic and tactical level has been analyzed.

The model of Karkazis and Boffey (1995) [52] deals both with decisions at the tactical and the operational level as the fixed-route model encompasses medium-term routing decisions and the variable-route model takes daily meteorological conditions for the hazmat transportation into account[460]. Kress (2006) [54] focuses on vaccination as a mitigation strategy and encompasses both strategic and operational level.

[455] Cp. [73] Schmitt et al. (2007), p. 655ff.
[456] Cp. [34] Fowler et al. (2005), p. 601ff.
[457] Cp. [7] Barbarasoğlu et al. (2002), p. 119.
[458] Cp. [14] Brimberg et al. (1995), p. 36.
[459] Cp. [15] Brown and Vassiliou (1993), p. 1ff.
[460] Cp. [52] Karkazis and Boffey (1995), p. 205f.

Table 3: Level of disaster management

		[1] [11] [12] [18] [29] [56] [86] [90]	[2]	[3] [66]	[4] [34] [73]	[5] [8] [13] [16] [19] [21] [26] [28] [31] [32] [33] [36] [37] [39] [40] [47] [48] [49] [50] [51] [53] [57] [67] [68] [71] [75] [80] [82] [83] [84] [85]	[6] [10] [23] [35] [42] [46] [69] [70] [78] [88]	[7]	[9] [24] [45]	[14]	[15]	[17] [30]	[20] [25] [38] [43] [44] [55] [58] [61] [72] [74] [76] [77] [81] [87] [89]	[22] [41] [59] [62] [64] [65] [79]	[27]	[52]	[54]	[60]	[63]
Mitigation	Strategic					X											X		
	Tactical											X				X			
	Operational		X													X	X		
Preparedness	Strategic	X			X					X									
	Tactical								X										
	Operational			X						X									
Response	Strategic				X								X		X				
	Tactical						X	X							X				
	Operational							X						X					
Recovery	Strategic																		X
	Tactical										X							X	
	Operational										X								

Source: Own illustration

5.2 Model type

The different types of models considered in the taxonomy are geographical models, statistical models, optimization, simulation, covering location models, graph theory, queueing theory, decision tree and game theory. Geographical models encompass GIS technology, statistical models include expected value models[461,462], Marcov processes[463,464,465], risk assessment models[466,467,468], VaR[469], loss estimation models[470,471] and value function under risk[472]. Although sometimes the borders between the abovementioned model classes are blurring, the author found this division as the most appropriate for this purpose.

All these nine categories further have general characteristics, often used in the operations research literature so as to describe specific features of a model[473].
A model is static when "all planning is for a single period of time"[474], whereas it is dynamic when "circumstances vary over time"[475]. Static models are only destined for a fixed time interval and the problem does not change in this pre-defined period. Time is not a predominant factor in these models, whereas in dynamic models time is a crucial parameter[476].

The division between a deterministic and a stochastic model is explained as follows. "A mathematical model is termed deterministic if all parameter values are assumed to be known with certainty, and probabilistic or stochastic if it involves quantities known only in probability"[477]. Therefore, in deterministic models uncertainty is nonexistent while in stochastic models uncertainty considerable influences the course of action[478].

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461 Cp. [6] Barbarasoğlu and Arda (2004), p.43ff.
462 Cp. [82] Van Steen (1987), p. 231ff.
463 Cp. [38] Georgiadou et al. (2007), p. 1388ff.
464 Cp. [4] Baccam and Boechler (2007), p. 26ff.
465 Cp. [73] Schmitt et al. (2007), p. 656.
466 Cp. [24] Chu and Sun (2007), p. 1ff.
467 Cp. [57] Leung et al. (2003), p. 1323ff.
468 Cp. [50] Kappos and Dimitrakopoulos (2008), p. 33f
469 Cp. [36] Fuchs et al. (2005), p. 893ff.
470 Cp. [49] Jain and Davidson (2007), p.45ff.
471 Cp. [53] Kleindorfer and Kunreuther (1999), p. 727ff.
472 Cp. [80] Tamura et al. (2000), p. 461ff.
473 Cp. [286] Rardin (2000), p. 16ff.
474 [286] Rardin (2000), p. 153.
475 [286] Rardin (2000), p. 153.
476 Cp. [284] Bomze and Grossmann (1993), p. 9.
477 [286] Rardin (2000), p. 16.
478 Cp. [284] Bomze and Grossmann (1993) p. 9.

Table 4: Model type

Model type	[1]	[2] [8] [16] [17] [19] [26] [32] [52] [75]	[3] [13] [20] [23] [29] [43] [44] [45] [61] [62] [66] [67] [70] [71] [72] [74] [79] [86]	[5]	[4] [6] [24] [38] [50] [53] [57] [73] [82]	[7] [12] [14] [22] [25] [28] [30] [31] [35] [41] [42] [46] [48] [54] [55] [59] [60] [63] [65] [69] [76] [77] [78] [81] [87] [88] [90]	[9] [10] [64] [89]	[11]	[15] [56]	[18] [21] [47]	[27]	[36]	[39]	[49]	[51] [84]	[58]	[80]
Geographical model										X	X	X	X		X		
Statistical model					X							X		X			X
Optimization						X			X	X							
Simulation	X		X						X		X	X		X		X	
Covering location model							X				X						
Graph theory		X													X	X	
Queueing theory	X			X													
Decision tree																	X
Game theory								X									

Source: Own illustration

A discrete variable entitled “is limited to a fixed or countable set of values”[479], often the variables can only be 0 or 1. On the other hand, a continuous variable “can take on any value in a specified interval”[480]. If a model contains both discrete and continuous variables, it is a mixed model[481].
Linearity occurs when a function “is a constant-weighted sum of decision variables”[482], otherwise the function is nonlinear. “An optimization model is an integer program (IP) if any one of its decision variables is discrete”[483], otherwise it is a non-integer programme.

To give an insight in what way the abovementioned characteristics are used in the literature, several examples are given.

In Dimopoulou and Giannikos (2004) [27], in order to limit the number of escaped fires, a static sub-system has been created and a dynamic sub-system has been used to control the evolution of the fire. Dynamic optimization has been used in the earthquake scenario of Friedrich et al. (2000) [35]. Barbarasoğlu et al. (2002) [7], not focused on a specific disaster type, and Shih and ReVelle (1995) [77], dealing with water supply management, used a mixed integer programming model, while a mixed integer quadratic programming model was utilized by Haghani and Oh (1996) [41] which is applicable to various natural disaster types. A linear integer programming model has been used by Iakovou et al. (1996) [46] for the positioning of oil spill cleanup facilities, whereas Brimberg et al. (1995) [14] solved the water supply management problem with a mixed linear zero one integer programming model. Integer programmes are further used in the oil spill scenario of Srinivasa and Wilhelm (1997) [78] and the bioterrorism response model of Whitworth (2006) [87].

A linear programme for the transportation planning of commodities and an integer program for the planning of vehicle flow has been used in the model of Özdamar et al. (2004) [64].

Simulation is widely used in the literature, in this taxonomy DES is the predominant tool. DES has been conducted in Aaby et al. (2006) [1], Albores and Shaw (2005) [3], Hupert et al. (2002) [45], Løvås (1998) [58], Miller et al. (2006) [61], Mould (2001) [62], Pendergraft et al. (2004) [67], Schenk et al. (2005) [72], Taaffe et al. (2006) [79], and Whitworth (2006) [86].

479 [286] Rardin (2000), p. 53.
480 [286] Rardin (2000), p. 53.
481 Cp. [286] Rardin (2000), p. 56.
482 [286] Rardin (2000), p. 48.
483 [286] Rardin (2000), p. 56.

As shown in Table 4, the design of the point of dispensing of Aaby et al. (2006) [1] relies on both simulation and queueing tools. Brown and Vassiliou (1993) [15] both utilize optimization and simulation tools, while Lee et al. (2006) [56] use a mixed linear programming as well as a simulation model in order to properly model the problem. Chang et al. (2007) [18], Chen et al. (2008) [21], and Iakovou (2001) [47] both utilize GIS and optimization, while Kara and Verter (2004) [51] and Verter and Kara (2008) [84] chose both GIS and graph theory to solve the hazmat routing problem.

The fire management system of Dimopoulou and Giannikos (2004) [27] encompasses a GIS module, a mathematical programming module, and a simulation module, therefore all three of these categories are marked in the table. To answer the question of the amount of fire fighting vehicles needed, a set covering model is applied and the maximal covering location model helps find the optimal covering of the affected area given a predefined number of vehicles.

In Fuchs et al. (2005) [36], a simulation tool for avalanche run out areas and a statistical model have been used to calculate PML. The model of Jain and Davidson (2007) [49] deals with estimated changes in hurricane wind risk to wood-frame houses and the statistical model is implemented in a simulation. Løvås (1998) [58] first utilizes graph theory to model wayfinding of individuals when evacuating from a building and also uses the DES tool EVACSIM. Tamura et al. (2000) [80] use a statistical tool and decision trees to mitigate earthquake risk.

In Fisher et al. (1995) [33], Fowler et al. [34], Fuchs and McAlpin (2005) [37], Gupta and Shah (1998) [40], Pisaniello and McKay (2007) [68], Vanem et al. (2008) [83] and Walker (2000) [85] no information is provided on the model type used, therefore these articles cannot be found in Table 4. In all these articles, economic evaluation is conducted, as is stated in section 5.6.1.

5.3 General Model

The classification categories of Table 5 are mostly taken from the article of Denizel et al. (2003) [137], dividing the general features of a model into several attributes.

Setting means the context in which the respective model has been conducted, it can either be real or hypothetical and there is no setting in case the study does not show any application context[484]. The class no setting has been excluded as all models taken into consideration in the taxonomy are intervention-oriented and therefore definitely have an application context.
The second attribute, situation, can either be standard, being already well studied in the field of OR, or novel, dealing with a completely new or barely studied problem[485].

The approach might also either be standard, as already stated above well studied in OR, or novel stating that either a completely new approach has been created or an extant one has been applied in a new way[486]. This attribute was excluded as in the taxonomy it might occur that approaches taken in older papers are outdated due to more recent findings or models.

Furthermore, data can either be real, randomly generated, or no data[487] can be used, here we assumed that all models have application contexts, therefore no model was considered as applying no data. Randomly generated data have been called hypothetical data in the table.

Additionally, the parameters "geographical area" and "time horizon" have been added to the taxonomy, as these specifications underline the importance of disaster management in general and focus on the application context on the particular intervention. The geographical area is either bounded or unbounded, which means that the model is specified for a specific region or is universally applicable.

With regard to the time horizon, ultra short term activities include all actions taken in the first twelve hours after the disaster has occurred and the intervention ends as soon as the disaster is over. This very short time period is crucial for the success of some activities taken such as in the field of evacuation and are therefore included in the taxonomy. Short-term interventions include activities up to one week after the initial occurrence of the disaster, while intermediate-term models deal with a period of up to one year. All models dealing with a time horizon of more than one year are considered long-term interventions.

[484] Cp. [137] Denizel et al. (2003), p. 714.
[485] Cp. Ibidem.
[486] Cp. Ibidem.
[487] Cp. Ibidem.

Table 5: General model

General Model		[1] [44]	[2] [10] [27] [59]	[3] [20] [25] [41] [43] [65] [66] [72] [86] [89]	[4]	[5] [38]	[6] [33] [36] [37] [84] [85] [87]	[7]	[8] [19] [26] [28] [31] [75] [77] [82] [83]	[9] [13] [34] [73] [90]	[11]	[12]	[14] [51] [71]	[15] [54] [80]	[16] [40] [48]	[17] [52]	[18] [76]	[21] [32] [46] [49] [50]	[22]	[23] [24] [74]	[29]	[30] [47] [69]	[35] [45] [55] [56] [70]	[39] [57]	[42]	[53]	[58]	[60]	[61]	[62]	[63]	[64] [88]	[67] [68]	[78] [79]	[81]
Setting	Real		X				X	X	X			X	X		X	X	X	X	X		X	X		X	X						X	X	X	X	X
	Hypothetical	X		X	X	X				X	X			X						X			X			X	X	X	X	X					
Situation	Standard	X	X	X			X	X	X	X	X			X				X		X	X	X					X		X		X	X		X	
	Novel				X	X						X	X		X	X	X		X				X	X	X	X		X		X			X		X
Data	Real		X				X					X												X			X				X		X		X
	Hypothetical	X		X	X	X		X	X	X	X		X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X		X		X	
Geographical Area	Geographically bounded	X	X				X				X	X	X					X			X			X	X		X		X	X				X	X
	Geographically unbounded			X	X	X		X	X	X				X	X	X	X		X	X		X	X			X		X			X	X	X		
Time horizon	Ultra short-term					X		X				X							X	X					X		X								
	Short-term	X	X	X													X						X							X		X		X	X
	Intermediate-term				X					X						X					X	X						X	X						
	Long-term						X		X		X		X	X	X			X						X		X					X		X		

Source: Own illustration

To give a deeper impression of each subcategory, several examples are further explained below. Belardo et al. (1984) [10] used a real setting, as oil spills occur quite often, whereas in Miller et al. (2006) [61], a hypothetical smallpox attack setting has been simulated to show the potential effects of a bioterrorist attack.

Standard situations are for example evacuation situations as described in Chow and Ng (2008) [23], a novel situation has been investigated in Hupert et al. (2002) [45] as they are dealing with the design of antibiotic distribution centres. Real data has been used in the airtanker-basing model of MacLellan and Martell (1996) [59], while hypothetical data has been used in the evacuation model of Georgiadou et al. (2007) [38].

The model of Aaby et al. (2006) [1] is classified as "geographically bounded" as the bioterrorism preparedness model is designed for Montgomery county, Miller et al. (2006) [61] focus on a smallpox attack in San Antonio. Özdamar et al. (2004) [64] is applicable to any region in the world and to different types of natural disasters. Several hazmat routing models such as by Kara and Verter (2004) [51] and Verter and Kara (2008) [84] focus on the province Ontario in Canada, the latter also includes the province Quebec.

An ultra short-time horizon is given in Barbarasoğlu et al. (2002) [7], applicable to all different types of disasters. A time horizon of 72 hours has been considered in the bioterrorism preparedness model by Patvivatsiri (2006) [66], thus the model is classified as being short-term. The counter-bioterrorism model of Zaric et al. (2008) [90] covers a time period of 100 days and is therefore considered as being an intermediate term model. A period of 36 months has been chosen in Shih and ReVelle (1995) [77] thus it is a long-term drought response model.

5.4 Interventions

It has been proven useful to divide the interventions examined in the literature into structural and non-structural interventions. Structural interventions encompass structural measures taken such as retrofitting of houses, structural protection against floods and location decision for response kits. Non-structural interventions comprise other activities such as evacuation or routing decisions or medication strategies. Both structural and non-structural interventions can either be non-specific such as generally applicable to different disaster situations or specific such as only deployable for a specific disaster type.

Zaric et al. (2008) [90] is the only paper considering the effectiveness of counter-bioterrorism interventions on national, regional, and local level.

5.4.1 Structural Interventions

Structural interventions might either be non-specific or particularly used for a specific disaster type. The location of response facilities or of response team stations is applicable to all disaster types. For geophysical disasters, general earthquake mitigation measures, retrofitting, rebuilding activities, and earthquake kits are available to decrease the likelihood of structural damages or the collapse of buildings. "Lahar is the Indonesian term for volcanic ash"[488] and lahar dams are used to prevent inhabited regions from lahar. Lahar dams are therefore another structural intervention taken.

Structural hurricane mitigation measures are for example plywood boards[489] to protect houses from wind. Water supply reservoirs are needed to secure water supply also in arid periods[490]. Further structural interventions especially important for avalanche protection are forests and other technical avalanche protection measures like fences[491].

For technological disasters, structural interventions such as fire detection installations[492], the positioning of oil spill cleanup facilities[493], and train protection systems[494] are used. Private water dams play an important role in Australia, safety design is therefore crucial to prevent

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[488] [57] Leung et al. (2003), p. 1323.
[489] Cp. [29] Drake et al. (2007), p. 5.
[490] Cp. [33] Fisher et al. (1995), p. 304ff.
[491] Cp. [36] Fuchs et al. (2005), p. 895.
[492] Cp. [24] Chu and Sun (2007), p. 1ff.
[493] Cp. [10] Belardo et al. (1984), p.1113ff.
[494] Cp. [71] Riddington et al. (2004), p. 606ff.

flooding[495]. Safety resources at airports and the design of a point of dispensing are interventions aiming at general terrorist attacks.

As it can be seen in Table 6, different response facility location problems are well discussed in the literature. Furthermore, optimal earthquake mitigation is a central topic in this field of research as well as the location of oil spill cleanup facilities. For the retrofitting of houses, several authors also take the level of the intervention into consideration[496].

MacLellan and Martell (1996) [59] have evaluated the location of airtankers for wildland or forest fire fighting. Forest fire detection installations analyzed in Chu and Sun (2007) [24] are glass bulb sprinklers, smoke detection, and deluge systems.
The model of Jain and Davidson (2007) [49] deals with structural interventions with regard to retrofitting and rebuilding of houses. In Riddington et al. (2004) [71] automatic train protection, a security system using track side transmitters to vary the speed of the train depending upon the conditions of the track, has been analyzed.

Several papers introduce both structural and non-structural interventions. This combination of measures can be found in Albores and Shaw (2005) [3], Chang et al. (2007) [18], Chu and Sun (2007) [24], Drake et al. (2007) [29], Leung et al. (2003) [57], Yi and Özdamar (2007) [89], and Zaric et al. (2008) [90].

[495] Cp. [68] Pisaniello and McKay (2007), p. 176ff.
[496] Cp. [50] Kappos and Dimitrakopoulos (2008), p. 49.

Table 6: Structural interventions

Interventions	[1] [45] [56] [86] [90]	[3] [9] [11] [18] [27] [42] [59] [89]	[10] [46] [69] [78] [83] [87]	[12] [60]	[24]	[28] [50] [53] [80]	[29] [49]	[33]	[37]	[39]	[40]	[48] [67]	[57]	[68]	[71]
Structural															
Non-specific															
Location of response facilities		X													
Location of response team station				X											
Specific															
Natural disaster															
Geophysical disasters															
Earthquake mitigation measures						X					X				
Retrofitting or rebuilding of buildings						X					X				
Earthquake kits											X				
Lahar dams													X		
Hydro-meteorological disasters															
Hurricane mitigation measures							X								
Water supply reservoirs and pumpage systems								X							
Forestation										X					
Technical avalanche protection									X						
Technological disasters															
Fire detection installation					X										
Positioning of oil spill cleanup facilities			X												
Train protection system															X
Safety design for private dams														X	
General terrorism															
Safety resource requirements airport												X			
Point of dispensing design	X														

Source: Own illustration

5.4.2 Non-Structural Interventions

Non-structural interventions are all other interventions which are not related to structural protection measures. Hospital preparedness is one of the main non-specific interventions as for all different kinds of disasters to reduce the number of victims effective medical treatment is crucial. The optimization of evacuation processes and allocation of response teams play a very important role. Helicopter rescue activities as well as dispatch orders for vehicles are important in the aftermath of a disaster. Longer term non-structural interventions are resettlement projects and housing allocation models.

Particularly for hydro-meteorological disasters, water supply management and avalanche risk assessment were considered in the models. In the field of technological disasters, inspection plans and nuclear accident response strategies try to minimize effects of industrial accidents. Transportation accidents are examined via hazmat routing decisions and ship traffic management. Non-structural interventions in the field of general terrorism encompass the modelling of anthrax dispersion, emergency room preparedness for a biological or chemical attack, decontamination activities, medication, and vaccination strategies.

Table 7 shows which non-structural interventions are discussed in the literature. Evacuation optimization is a very important task for disaster managers; different scenarios show the application of building or larger-scale evacuations. Dispatch orders for vehicles are particularly important to design the logistical problems arising as a result of a disastrous event as effective as possible. Hazmat routing strategy is another central topic of disaster management. In the field of bioterrorism-related disasters, an increasing amount of authors discuss optimal medication and vaccination strategies.

In the hazmat routing decision making problem of Kara and Verter (2004) [51], the government also plays a role. In Albores and Shaw (2005) [3], the decontamination process consists of only three phases, disrobing, the decontamination via showers, and re-robing. Kress (2005) [55] is the only paper which, besides vaccination, includes the effects of quarantine in the model. Chiu and Zheng (2007) [22] discuss both evacuation optimization and the simultaneous dispatching for emergency response units, while Yi and Kumar (2007) [88] also focus on both dispatch and evacuation problems.

Table 7: Non-structural interventions

Interventions	[2] [8] [16] [17] [19] [21] [26] [31] [32] [51] [52] [75] [82] [84]	[3]	[4] [13] [25] [34] [54] [55] [61] [73] [90]	[5] [20] [23] [24] [29] [38] [43] [44] [58] [62] [74] [79]	[6] [18] [35] [41] [64] [76] [81] [89]	[7]	[14] [77]	[15]	[22] [88]	[30]	[36]	[47] [85]	[57]	[63]	[65]	[66]	[70]	[72]
Non-structural																		
Non-specific																		
Hospital preparedness optimization																		X
Evacuation optimization				X					X									
Response team allocation								X										
Helicopter response and rescue activity						X												
Dispatch orders for vehicles					X				X									
Resettlement project													X	X				
Housing allocation														X				
Specific																		
Natural disaster																		
Hydro-meteorological disasters																		
Water supply management							X											
Avalanche risk											X							
Technological disasters																		
Industrial accident																		
Inspection plan										X								
Nuclear accident response strategy															X			
Transportation accident																		
Hazmat routing decision	X																	
Ship traffic management												X						
Terrorism Forms																		
Modelling anthrax dispersion																	X	
Emergency room preparedness																X		
Decontamination activity		X																
Medication and vaccination strategy			X															

Source: Own illustration

For Fuchs et al. (2005) [36], the avalanche risk in settlements lies in the centre of interest. The housing allocation and resettlement project analyzed in Nikopoulos and Tzanetis (2003) [63] investigates the flow from homelessness to temporary housing and finally to a permanent resettlement. In Papamichail and French (1999) [65], the nuclear accident response strategies encompass evacuation, sheltering or the issue of iodine tablets, or a combination of these measures in the affected blocks at the disaster site.

5.5 Disaster

The dimension disaster first shows for what disaster type a model is suitable and also tries to underline whether the extent of the disastrous event has been taken into consideration in the respective paper.

5.5.1 Disaster Type

Table 8 shows the disaster type dealt with in each paper classified. The categories are taken from the above mentioned classification, stating whether the model can be used for a category of disasters such as natural disasters, whether it is applicable only for a specific disaster type or if it is generally applicable for all different disaster types.

Table 8 gives an insight about the type of disaster mostly considered in the reviewed literature. As already mentioned above, the focus in the field of natural disasters lies on earthquakes, for technological disasters it is chemical spills, hazmat transportation, and in the terrorism forms it is bioterrorism. Furthermore, a considerable amount of articles is applicable to several or all disaster types.

Albores and Shaw (2005) [3] show the potential consequences of the simultaneous occurrence of different disasters, the collapse of a building, contamination of a population with a chemical agent and a bursted dam and try to solve the respective resource allocation problem in order to provide optimal response to all incidences. Although the first part of the paper deals with a decontamination problem the paper has been classified as not dealing with a specific disaster type but with a general disaster. The evacuation models of Bakuli and MacGregor Smith (1996) [5], Chen and Zhan (2008) [20], Chiu and Zheng (2007) [22], Han et al. (2006) [43], and Løvås (1998) [58] are also generally applicable. Furthermore,

Table 8: Disaster type

Disaster type	[1] [4] [13] [25] [34] [45] [54] [55] [56] [61] [66] [70] [73] [86] [90]	[2] [8] [12] [16] [17] [19] [21] [26] [31] [32] [51] [52] [75] [82] [84]	[3] [5] [7] [9] [20] [22] [23] [24] [43] [58] [88]	[6] [15] [28] [35] [40] [50] [76] [80] [81] [89]	[10] [46] [47] [69] [78] [83] [87]	[11] [48] [72]	[14] [33] [77]	[18]	[27] [42] [59]	[29] [49] [79]	[30] [62]	[36] [37] [39]	[38]	[41] [60] [63] [64]	[44] [65]	[53]	[57]	[67] [74]	[68]	[71]	[85]
Non-specific			X																		
Specific																					
Natural disaster														X							
Geophysical disasters																					
Earthquakes				X												X					
Volcanic eruptions																	X				
Hydro-meteorological disasters																					
Floods								X													
Hurricanes										X						X					
Droughts							X														
Forest and wildland fires									X												
Avalanches												X									
Technological disasters											X										
Industrial accidents																					
Chemical spills					X								X								
Radiation accidents															X						
Dam failures																			X		
Transportation accidents																					
Train accidents																				X	
Road accidents		X																			
Ship accidents																					X
Terrorism Forms																		X			
General terrorism						X															
Bioterrorism	X																				

Source: Own illustration

Barbarasoğlu et al. (2002) [7], Batta and Mannur (1990) [9], and Yi and Kumar (2007) [88] do not exclude any disaster situation too. In Chow and Ng (2008) [23] and Chu and Sun (2007) [24], the cause of the fire has not been stated, therefore the models were classified as being applicable to the non-specific disaster type.

Duffuaa and Khan (2002) [30] and Mould (2001) [62] do not focus on a specific technological disaster but are generally applicable for different types of technological disasters. Haghani and Oh (1996) [41], Mann et al. (1996) [60], Nikopoulos and Tzanetis (2003) [63], and Özdamar et al. (2004) [64] can be applied to different kinds of natural disasters. Kleindorfer and Kunreuther (1999) [53] explicitly states its practicability for earthquake and hurricane situations. The analyses of Pendergraft et al. (2004) [67] and Shendarkar et al. (2006) [74] are deployable for both terrorist attacks and bioterrorist attacks.

The model of Yi and Özdamar (2007) [89] is applicable to different types of disasters but the model is applied to an earthquake scenario.

5.5.2 Extent of Event

Several authors also try to include the extent of the disaster into the modelling process, here the dimensions intensity, as well as size and duration of the disaster were the mostly used in the literature. Intensity stands for all severity related characteristics as the value on the Richter scale for earthquakes, the intensity of a volcanic eruption, the wind speed of a hurricane, fire spread, the intensity of an avalanche, or the intensity of a terrorist or bioterrorist attack. The class weather conditions encompasses factors like wind, rainfall, sea conditions and so on. Size-related parameters highlight quantitative considerations, namely the number of accidents, especially in the field of technological disasters, as well as the amount of erodable sediments after a volcanic eruption and the amount of chemical spilled. Furthermore, the duration of the disaster has been considered related to drought and bioterrorist attacks.

Table 9 points out that weather conditions are very often part of the model and might have an influence on the decision making process. Additionally the number of accidents is also often considered as well as the amount of chemical spilled.

Albores and Shaw (2005) [3] investigate the possibility that several incidences occur simultaneously, underlining that the occurrence of more than one disaster at a time might

Table 9: Extent of event

Extent of event	[2] [18] [49] [59] [62] [65]	[6] [50] [80]	[8] [19] [26] [31] [32] [71] [75] [84]	[10] [38] [46] [78] [87]	[25] [45] [70]	[27]	[29] [79]	[34] [61] [69] [73] [83]	[36] [37] [39]	[52]	[57]	[66]	[74]	[77]	[85]
Intensity															
Weather conditions	X			X		X				X	X				
Strength of earthquake		X													
Intensity of volcanic eruption															
Severity of hurricane							X								
Fire spread						X									
Intensity of avalanche									X						
Intensity of general terrorist attack													X		
Intensity of bioterrorist attack					X										
Size															
Number of accidents			X							X					X
Amount of erodable sediments											X				
Amount of chemical spilled				X				X							X
Duration															
Duration of drought														X	
Duration of bioterrorist attack												X			

Source: Own illustration

worsen the overall response capability. Braithwaite et al. (2006) [13] take the probability, not the severity or intensity of a bioterrorist attack into consideration. In Friedrich et al. (2000) [35] not simultaneous occurring disasters were evaluated but the probability of a secondary disaster, i.e., the probability of dam failures or landslides caused by the quake.

The effect of differently affected regions was introduced in Mann et al. (1996) [60] and Papamichail and French (1999) [65], while Yi and Özdamar (2007) [89] indicated for example that response vehicles located in a less affected area can be used in heavier affected areas. In Patvivatsiri (2006) [66] the duration of the bioterrorist attack has been further elaborated but there has not been shown any significance of this parameter. The concentration of anthrax spores was included in Reshetin and Regens (2003) [70].

Belardo et al. (1984) [10] not only evaluate the amount of oil spilled but also the type of oil spilled, namely volatile products as well as light and heavy refined products. For the hazmat routing problem, the accident probability has been taken into consideration in Chang et al. (2005) [19], Dadkar et al. (2008) [26] and Sherali et al. (1997) [75]. The hazmat routing and scheduling model described in Carotenuto et al. (2007b) [17] is the only hazmat model also taking the routing of other hazmat carrying vehicles into consideration. In Schmitt et al. (2007) [73] a small-scale anthrax attack has been simulated, Fowler et al. (2005) [34] describe a large-scale anthrax attack and Miller et al. (2006) [61] evaluate the situation of a small-scale smallpox attack.

5.6 Economic Analysis

The following section first shows which authors implemented what type of economic analysis in their models and then further illustrates which effectiveness-related, resource-related, and cost-related parameters are mostly used as decision variables in disaster management literature.

5.6.1 Type of Analysis

Three different kinds of economic analyses were found to be used in the literature. Either cost-utility, cost-effectiveness, or cost-benefit analysis has been used in order to evaluate different strategies.

Tamura et al. (2000) [80] compare the outcome of expected utility theory with the value function under risk. Only the articles [7], [13], [33], [34], [37], [39], [40], [50], [53], [68], [71], [73], [80], [83], [85], and [90] took advantage of these economic analyses, as can be seen in Table 10, [7], [13], [34], [40], [53], [68], [73], [83], and [85] used cost-effectiveness analysis, [33], [37], [39], [50], [71], and [90] used cost-benefit analysis, and most authors focus on other parameters in order to underline the effectiveness of the proposed models, as will be explained in the following sub-sections.

Table 10: Economic analysis

Economic Analysis	[7] [13] [34] [40] [53] [68] [73] [83] [85]	[33] [37] [39] [50] [71] [90]	[80]
Cost-utility analysis			X
Cost-effectiveness analysis	X		
Cost-benefit analysis		X	

Source: Own illustration

5.6.2 Effectiveness-Related Parameters

Effectiveness-related parameters were divided into victim-related and time-related parameters. Victim-related parameters are often used in the literature as for disaster management activities the predominant goal is to safe lives and to reduce the overall effects of disasters on the population. In most circumstances this goal can only be achieved through quick interventions, therefore time-related parameters are also very important to milder the effects of a disastrous event.

5.6.2.1 Victim-Related Parameters

Victim-related parameters encompass the consequences of disasters and interventions on the population. First of all, we consider which models account for the number of people exposed to a disaster. In case the population has been exposed to a bioterrorist attack, some authors further take their disease stages[497,498,499,500,501,502,503,504,505], i.e., whether they are in the incubation period (when the person is infected but does not show any symptoms), or in the prodromal stage (where the patient develops the symptomatic disease and suffers from a

497 Cp. [4] Baccam and Boechler (2007), p. 27f.
498 Cp. [13] Braithwaite et al. (2006), p. 183.
499 Cp. [25] Craft et al. (2005), p.683.
500 Cp. [45] Hupert et al. (2002), p.22.
501 Cp. [54] Kress (2006), p. 8.
502 Cp. [55] Kress (2005), p. 278f.
503 Cp. [56] Lee et al. (2006), p. 29.
504 Cp. [61] Miller et al. (2006), p. 589.
505 Cp. [90] Zaric et al. (2008), p. 4.

flulike illness) or in the fulminant stage (where symptoms become more severe and death occurs within 24 to 48 hours)[506], into account.

Furthermore, the number of injured is often evaluated, sometimes the severity of the injuries is explicitly considered. In this case, injured people are divided into three classes[507,508], namely slightly injured, seriously injured, and severe patients. Friedrich et al. (2000) [35] use a "four-level injury severity scale"[509] and include injuries which require a higher degree of medical care, injuries that are immediately life-threatening if not properly treated and people mortally injured in their model. Yi and Kumar (2007) [88] divide between heavy and light wounded patients, Yi and Özdamar (2007) [89] distinguish among heavy wounded and moderate-light wounded people.
Further important parameters are the number of people killed, number of lives saved, number of people evacuated or transported, in quarantine, resettled, living in temporary housing, homeless, or in waiting line for medical examination.

Table 11 shows that almost half of the literature reviewed, namely the papers [1], [3], [4], [5], [8], [11], [13], [16], [17], [18], [19], [20], [21], [23], [24], [25], [26], [31], [32], [34], [36], [37], [38], [43], [44], [45], [51], [52], [54], [55], [56], [61], [62], [65], [70], [73], [76], [84], [86], and [90] take the number of people exposed to the disastrous event into consideration. This can be explained due to the fact that the predominant goal of disaster management is to minimize the negative effects on human beings. The number of casualties is another widely used effectiveness parameter which has been analyzed in [4], [13], [25], [28], [35], [40], [41], [50], [54], [55], [61], [71], [73], [74], [75], [76], [80], [82], [83], [85], and [90].

Fowler et al. (2005) [34] and Schmitt et al. (2007) [73] also examined the quality adjusted life years (QALY) as additional effectiveness criteria. Whitworth (2006) [86] particularly takes the arrival patterns of affected persons into consideration. Albores and Shaw (2005) [3] is the only paper taking into consideration the influence of the number of non-ambulant people on the decontamination time. The simulation has shown that this number constitutes a veritable bottleneck in the system[510]. Chen and Zhan (2008) [20] use the number of people exposed to the disastrous event as sitting in their vehicles trying to evacuate the affected region. Hobeika

506 Cp. Ibidem.
507 Cp. [66] Patvivatsiri (2006), p.502.
508 Cp. [79] Taaffe et al. (2006), p.511.
509 [35] Friedrich et al. (2000), p. 46.
510 Cp. [3] Albores and Shaw (2005), p. 891.

Table 11: Victim-related parameters

Effectiveness-related parameters		[1] [86]	[3] [8] [11] [16] [17] [18] [19] [20] [21] [24] [26] [31] [32] [36] [51] [52] [70] [84]	[4] [25] [54] [61]	[5] [23] [38] [43] [44] [62] [65]	[7]	[13]	[22] [23] [58]	[28] [41] [50] [75] [82] [83] [85]	[29]	[34] [37]	[35]	[40] [80]	[45] [56]	[55]	[57]	[63]	[66]	[71]	[73]	[74]	[76]	[79]	[88] [89]	[90]
Victim-related parameters																									
Number of people exposed	General	X	X	X	X		X				X			X	X					X		X			X
	Classes			X			X							X	X										X
Number of people injured	General					X							X												
	Classes											X						X					X	X	
Number of people killed				X			X		X			X	X		X				X	X	X	X			X
Number of lives saved							X				X					X			X	X					
Number of people evacuated/ transported					X	X		X				X									X		X	X	
Number of people in quarantine															X										
Number of people resettled																	X								
Number of people in temporary housing										X							X								
Number of people homeless													X				X								
Number of people in waiting queue for medical examination		X												X										X	X

Source: Own illustration

et al. (1994) [44] also counts the number of people exposed by the number of vehicles needed to be evacuated from the threatened area.

Georgiadou et al. (2007) [38] both considers the number of people in the affected region near the disaster site but also evaluates the health effects on the population, such as the dose of contamination by the chemical each person receives. Kress (2006) [54] further makes a difference among people in the incubation stage being immunable (susceptive for the vaccine), and non-immunable (not susceptive for the vaccine), as well as the importance of the index case, (the first infected person), has been underlined.
In the hazardous material routing problem such as Erkut and Ingolfsson (2000) [32], the minimization of population exposed lies in the centre of interest, while in Sherali et al. (1997) [75], the expected number of persons killed has been evaluated.

In Friedrich et al. (2000) [35], the number of fatalities has been intensively analyzed and not only fatalities directly caused by the disaster itself but also due to secondary disasters, the duration of the rescue operation or transport, the lack of rescue attempts and delayed transport have been included in the model. The daily number of infectious persons, people in quarantine, and people that stay home is shown in Kress (2005) [55].

5.6.2.2 Time-Related Parameters

Time-related parameters are widely used in the literature to valuate the disaster management activities. Response time encompasses the time from the initial beginning of an intervention up until all activities are completed. Evacuation time and decontamination time describe the duration of the evacuation or decontamination activity. Time of water rationing and the duration of the epidemic are important for drought and bioterrorist attacks.

In some papers the starting time of the intervention and the arrival time of the resources at the disaster site have been decisive with regard to the overall effectiveness of the activity. Travel distance and time as well as minimum total delay is especially important for hazmat transportation problems. Also inside the hospital, time plays an important role and shows the effectiveness of disaster management of the hospitals, expressed by the waiting time until medical treatment starts and the total time in the medical institution such as emergency room or clinic in general.

Table 12: Time-related parameters

Effectiveness–related parameters	[1] [86]	[2] [8] [16] [19] [21] [26] [31] [32] [51] [52] [64] [75] [84]	[3]	[4] [73]	[5] [20] [38] [43] [44] [58] [62] [74]	[6] [41] [76]	[7]	[10]	[12]	[13] [22] [35] [42] [46] [60] [63] [65]	[15] [88]	[17]	[23]	[24]	[25]	[34] [57] [78]	[45] [56]	[55] [61]	[66]	[67] [72]	[77]	[79]	[81]	[87]	[89]	[90]
Time-related parameters																										
Response time	X		X	X			X		X	X	X						X					X			X	
Evacuation time					X								X	X								X				
Decontamination time			X					X							X									X		
Time of water rationing																					X					
Duration of epidemic																		X								
Starting time of intervention				X								X	X	X	X	X										X
Arrival time of human and emergency resources			X			X		X			X												X			X
Travel distance and time		X	X				X		X			X											X		X	
Minimal total delay		X							X			X											X		X	
Waiting time (airport, medical treatment)	X												X		X		X			X					X	
Total time in medical institution	X																		X							

Source: Own illustration

Table 12 shows that the total time needed to complete the intervention. For example, response time, is often used as an effectiveness criterion. Furthermore, for all evacuation processes the evacuation time is minimized. The papers [4], [17], [23], [24], [25], [34], [57], [73], [78] and [90] particularly focus on the point in time when intervention starts, while in the papers [3], [6], [10], [15], [41], [76], [81], [88], and [90] the arrival time at the disaster site is a predominant factor. For all hazmat related interventions, the minimum total travel distance and time, i.e., a minimization of delay is important. A lot of authors do not only focus on one of these parameters but consider several time-related parameters in their model, as can be found in [1], [2], [3], [4], [7], [8], [10], [12], [15], [16], [17], [19], [21], [23], [24], [25], [26], [31], [32], [45], [51], [52], [56], [64], [73], [75], [79], [81], [84], [86], [88], [89], and [90].

The average time each patient stays in each station of the dispensing centre, is modelled in Aaby et al. (2006) [1]. Albores and Shaw (2005) [3] show that a mass disrobing strategy positively influences the decontamination time after a biological or chemical attack.

As one example of hazmat problems, in Erkut and Ingolfsson (2000) [32], the shortest path, i.e. minimal travel distance, is taken as the effectiveness criterion. In Lee et al. (2006) [56], not only the total response time but also the optimization of sub-goals like the cycle time, were in the centre of interest. The simulation in Taafee et al. (2006) [79], both calculates the average evacuation time per patient as well as the average total completion time of the evacuation of the hospital.

5.6.3 Resource-Related Parameters

The section resource-related parameters shows which authors have explicitly considered either the human resource requirements in a specific disastrous situation or the amount of emergency resources required to optimally deal with the disaster.

5.6.3.1 Human Resource-Related Parameters

Human resource-related parameters encompass first of all the number of all different kinds of medical staff as for example doctors, nurses, and the staff in dispensing centres. As in a dispensing centre, there work a lot of different workers[511] (i.e., doctors, nurses, physicians, mental health counsellors, and security personnel).

[511] Cp. [56] Lee et al. (2006), p. 29f.

Furthermore, not only the number of medical staff but the number of first responders such as fire fighters, is crucial for the success of an intervention. Other authors determined the number of helicopter pilots, security personnel, and the number of workers to restore facilities. Some specific papers also take into consideration the number of personnel transported to the disaster site.

Staff utilization rate shows the workload of the persons involved in a certain stage of the disaster management process. It is used as an indicator for efficient intervention and therefore cannot be neglected in the taxonomy.

As can be seen in Table 13, only the models [1], [3], [7], [12], [15], [22], [27], [45], [56], [60], [61], [66], [67], [72], [74], [78], [86], [87], and [90] explicitly consider human resource related parameters in the model. Here, the number of staff in dispensing centres, as in [1], [45], [56], [86], and [90], and the number of first responders, as in [3], [12], [22], [27], [74], [78], and [87], is very often evaluated.

Table 13: Human resource-related parameters

Resource–related parameters	[1] [45] [56] [86]	[3] [12] [22] [27] [74] [78] [87]	[7]	[15] [60]	[61]	[66] [72]	[67]	[90]
Human resource-related parameters								
Number of doctors						X		
Number of nurses					X	X		
Number of staff in dispensing facility	X							X
Number of first responders		X						
Number of helicopter pilots			X					
Number of security personnel							X	
Number of workers				X				
Number of personnel transported				X				
Staff utilization rate	X					X		

Source: Own illustration

In Schenk et al. (2005) [72], the number of additional doctors and nurses for the optimal response to a general terrorism attack is evaluated. Depending on the quality of the personal protection equipment, the number of first responders also changes, as with a better protection first responders are able to stay longer in the contaminated area, as has been found by Albores and Shaw (2005) [3]. In Wilhelm and Srinivasa (1996) [87], the number of first responders is implicitly contained in the number of components, as components consist of both oil spill clean up facilities as well as the personnel who is using it.

Staff utilization rate is evaluated for doctors, triage nurses, and nurses assigned to a specific patient type in Patvivatsiri (2006) [66] and Lee et al. (2006) [56]. As Friedrich et al. (2000) [35] describe earthquake interventions at a tactical level, the number of human resources as well as emergency resources is pre-defined at an upper level of the decision ladder and therefore only the allocation but not the number of these resources can be modelled. Taaffe et al. (2006) [79] take the number of staff such as the number of doctors and nurses, as given.

5.6.3.2 Emergency Resource-Related Parameters

The number of emergency resource units is definitely one of the most important parameters in disaster management models. Although the personnel is often not explicitly considered, it has to be kept in mind that all vehicles in the model need an appropriate driver and are useless without the appropriate personnel. The predominant group of emergency resource-related parameters are vehicles to be able to transport human beings as well as emergency equipment. Ambulances and helicopters play a predominant role in the evacuation and transportation process, the category other vehicles subsumes fire fighting vehicles, trains, vans and rescue crafts.

The number of specially equipped dispensing centres, hospital beds, as well as the sufficient vaccination and medication inventory is important for the medical treatment in the aftermath of a disaster. As security on public places gets more and more important, the amount of security facilities and the amount of personal protection equipment for first responders are included. Mobile decontamination facilities such as tents are necessary to fight large scale chemical spills or attacks. Cleaning facilities are particularly important after oil spills on the sea. Storage capacity and the amount of commodities transported are important indicators on how successful an intervention is or to find out where potential bottlenecks might be. The throughput of the system is a measure on how effective the overall process is. Resource utilization rate is also applied to emergency resources, coverage means the efficiency of the response of a given number of vehicles in a pre-defined response time or to satisfy a pre defined level of demand. Similar to the staff utilization rate mentioned above, the resource utilization rate helps to evaluate the efficient capacity of existent resources. That way, existent bottlenecks or inefficiencies can be detected more easily.

Table 14: Emergency resource-related parameters

Resource–related parameters	[1]	[3]	[5]	[6]	[7]	[9]	[10]	[12] [27] [59]	[15] [41] [76] [88]	[18] [60]	[22] [38] [42]	[35] [61] [72]	[46] [78] [87]	[48]	[54]	[56]	[62]	[64]	[66]	[67]	[69]	[79]	[81]	[86]	[89]	[90]
Emergency resource–related parameters																										
Number of ambulances						X																X			X	
Number of helicopters					X												X	X							X	
Number of other vehicles						X		X	X		X						X	X				X	X		X	
Number of dispensing centres	X																							X		X
Number of hospital beds												X							X							X
Number of vaccination units															X											
Number of medication units																										X
Number of security facilities														X						X						
Number of personal protection equipment		X																								
Number of mobile decontamination facilities		X																								
Number of cleaning facilities							X						X								X					
Storage capacity										X			X								X		X			X
Amount of equipment/commodity transported				X	X				X	X			X					X					X			X
Throughput of system	X		X													X								X		
Resource utilization/coverage	X					X		X						X		X			X						X	X

Source: Own illustration

Table 14 shows that a great number of articles consider the amount of transportation vehicles needed for the disaster management process. Transportation vehicles are either used to transport people away from the disaster site, or to get first responders and emergency resources into the affected area.

In the emergency evacuation problem of Bakuli and MacGregor Smith (1996) [5], it has been found that during the evacuation process the corridor width is the critical parameter, strongly affecting the throughput and mean evacuation time. MacLellan and Martell (1996) [59] focus on the number of airtankers. Haight and Fried (2007) [42] only take the number of fire engines into consideration.

For baggage screening security devices, the capacity of bags screened per hour is crucial, as has been found in Jacobson et al. (2005) [48]. Taaffe et al. (2006) [79] investigate the number of ambulances and vans, critical patients can only be transported with ambulances.

In Aaaby et al. (2006) [1] utilization rates of different stations in the clinic, such as including staff and emergency resources, are discussed. The utilization rate of ambulances, helicopters, and trucks is analyzed in Yi and Özdamar (2007) [89], with trucks having a lower utilization rate than the other two transportation methods.

Coverage has been evaluated in Batta and Mannur (1990) [9], showing that even when there is only an insufficient number of facilities available, optimal location of these facilities can lead to a considerably high coverage rate of above 90%. Coverage in Zaric et al. (2008) [90] means how many of the effectively exposed people would get treatment in the dispensing centre.

5.6.4 Cost-Related Parameters

The cost-related parameters examined in this taxonomy are divided into direct and indirect costs.

Direct costs comprise all costs directly related to the intervention taken. The cost of implementation includes all costs related to the activation of the intervention. This

Table 15: Cost-related parameters: Direct costs

Cost-related parameters	[5] [10] [57] [72]	[6]	[7] [14]	[13]	[15] [21] [31] [47] [51] [60] [84]	[18]	[28]	[29] [75]	[30]	[33] [48] [87]	[34]	[37] [80]	[39]	[40]	[41] [59] [81]	[46]	[49] [53]	[50]	[68]	[69]	[71]	[73]	[76]	[82]	[83]	[85]	[90]
Direct costs																											
Implementation costs	X		X	X		X	X		X	X	X	X		X	X	X	X	X			X	X	X		X	X	X
Operating costs		X	X	X						X					X	X										X	X
Inspection costs									X										X								
Maintenance costs						X				X		X	X			X		X	X		X						X
Direct losses due to destruction						X		X			X	X		X		X	X	X		X				X	X		
Transportation cost		X			X	X									X	X							X	X		X	
Cleanup costs														X		X				X					X	X	
Repair costs							X							X				X			X					X	
Medical care costs				X							X			X								X					X

Source: Own illustration

encompasses fixed and variable costs[512]. Operating costs are expenses related to the daily operation and service. Inspection costs are the costs related to the detection of potential failures of the measure or structure implemented, whereas maintenance costs encompass expenditures exceeding daily operating costs, as for example small repairs or required updating of the structure.

Direct losses due to destruction sum all direct damages caused by the disaster. Transportation costs are expenses used to finance the transport of human and emergency resources to the disaster site as well as to transport victims to a medical facility and also encompass additional funds needed to make hazmat transportation safer. Cleanup and repair costs comprise all expenses related to the cleanup efforts after the disaster and the regeneration of the disaster site. Medical care costs include costs of prophylaxis such for vaccination, medication and treatment of the victims.

Indirect costs are loss of income due to business failure, when normal operations are interrupted due to the disaster, or economic losses due to disruption of services such as loss of utilities like water, electricity, gas, telephone, and transport. Delay costs might occur when either resources arrive at the disaster site too late or when transportation agreements cannot be met and encompass economic inefficiencies due to a longer than necessary transportation. Consumer surplus loss, tax revenue loss, value of property at risk, and the value of property saved are further cost-related parameters considered in this taxonomy.

Table 15 shows that the main cost-related parameters are the implementation costs of an intervention. These are the most self-evident costs arising in the entire process, although costs evolving every day, as for example operating and maintenance costs are not neglected in most of the papers. Direct losses due to destruction are evaluated in a considerable part of the literature.

The expected risk costs for the transport of one unit of oil was included in the analysis of Iakovou (2001) [47]. Duffuaa and Khan (2002) [30] try to minimize the expected total costs of the inspection of a critical component. This includes both the inspection costs and the costs of misclassification of a component such as false acceptance of scrap component or false rejection of a good component.

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[512] Cp. [14] Brimberg et al. (1995), p. 42.

In Leung et al. (2003) [57], the amount of investment for each possible lahar threat mitigation measure such as lahar dams, lahar control infrastructure, evacuation and resettlement are taken into consideration. Tamura et al. (2000) [80] found that the damage costs vary with the kind of mitigation strategy followed as well as the strength of the earthquake. The cost of averting a tonne of oil spilt is the underlying effectiveness criteria in Vanem et al. (2008) [83].

As can be found in Table 16, indirect costs are only rarely examined in the literature. Nevertheless, in Baccam and Boechler (2007) [4], Yi and Kumar (2007) [88], and Fuchs et al. (2005) [36], only indirect costs are examined.
Baccam and Boechler (2007) [4] demonstrate the cost of delay due to a later start of the intervention through the increase in percent casualties, while in Yi and Kumar (2007) [88] the delay in the provision of medical care to the people affected is analyzed. The values of property at risk in two settlements in Switzerland and Austria are investigated in Fuchs et al. (2005) [36].

Table 16: Cost-related parameters: Indirect costs

Cost-related parameters	[4] [5] [6] [15] [41] [88]	[29] [53] [71]	[33]	[36]	[37]	[40]	[50]	[57]	[85]
Indirect costs									
Loss of income due to business failure		X					X		X
Loss due to disruption of services						X			
Cost of delay	X								X
Consumer surplus loss			X						
Tax revenue loss					X				
Value of property at risk				X					
Value of property saved					X		X	X	

Source: Own illustration

In Barbarasoğlu and Arda (2004) [6] the recourse costs, including total flow costs, mode shift costs and the penalty costs of holding inventory at a latter stage are considered. Furthermore they also evaluate unsatisfied demand at the disaster site. Walker (2000) [85] includes both the loss of income of shipping companies due to the non-usability of the ship after an accident during the repair phase and focuses also on costs of delay when maritime shipping traffic tactic is used such as wider shipping lanes.

5.7 General Results

Some authors also considered a greater amount of different intervention strategies and tried to find the most efficient, the dominant strategy. Results can either be specific or general, depending on whether the outcomes are specific to the organization or situation involved or used in any organization or situation[513]. Table 17 shows that the papers [7], [10], [19], [24], [52], [57], [65], [72], [76], [82], and [85] consider the dominant strategy, the papers [2], [6], [10], [11], [12], [14], [21], [26], [27], [29], [32], [33], [34], [36], [37], [38], [39], [42], [44], [46], [49], [50], [57], [58], [59], [61], [62], [63], [64], [65], [69], [71], [72], [73], [76], [77], [78], [79], [81], [84], [85], [87], and [89] have specific results while the papers [1], [3], [4], [5], [7], [8], [9], [13], [15], [16], [17], [18], [19], [20], [22], [23], [24], [25], [28], [30], [31], [35], [40], [41], [43], [45], [47], [48], [51], [52], [53], [54], [55], [56], [60], [66], [67], [68], [70], [74], [75], [80], [82], [83], [86], [88], and [90] have general results.

Table 17: General results

General Results		[1] [3] [4] [5] [8] [9] [13] [15] [16] [17] [18] [20] [22] [23] [25] [28] [30] [31] [35] [40] [41] [43] [45] [47] [48] [51] [53] [54] [55] [56] [60] [66] [67] [68] [70] [74] [75] [80] [83] [86] [88] [90]	[2] [6] [11] [12] [14] [21] [26] [27] [29] [32] [33] [34] [36] [37] [38] [39] [42] [44] [46] [49] [50] [58] [59] [61] [62] [63] [64] [69] [71] [73] [77] [78] [79] [81] [84] [87] [89]	[7] [19] [24] [52] [82]	[10] [57] [65] [72] [76] [85]
Dominant strategy				X	X
Result	Specific		X		X
	General	X		X	

Source: Own illustration

"Sensitivity analysis is an exploration of results from mathematical models to evaluate how they depend on the values chosen for parameters"[514]. Sensitivity analyses were conducted in [4], [5], [8], [13], [14], [18], [30], [33], [34], [38], [40], [41], [45], [50], [54], [55], [59], [62], [66], [67], [69], [71], [73], [77], [86], and [87].

Schenk et al. (2005) [72] show the optimal number of additional human and emergency resources out of various different settings. The most promising shipping management

[513] Cp. [137] Denizel et al. (2003), p. 714.
[514] [286] Rardin (2000), p. 10.

strategies have been selected in Walker (2000) [85]. In Papamichail and French (1999) [65] it has been found out which countermeasure or set of countermeasures are feasible under different nuclear accident scenarios. Belardo et al. (1984) [10] analyze the Pareto optimal set of optimal locations for the different spill scenarios. Van Steen (1987) [82] compares different alternatives in shipping hazardous material, while Chu and Sun (2007) [24] investigate the best of two alternatives for fire detection.

Chang et al. (2005) [19] search for the non-dominated alternative of paths for hazmat routing decisions.

Sheu (2007) [76] shows various scenarios for disaster relief efforts and finds that the existing logistics systems performance can be increased by up to 31%. Leung et al. (2007) [57] analyze the Pareto-optimal solution for the management of lahar flow threat.

The results of the bioterrorism scenario of Schmitt et al. (2007) [73] are classified as specific, as they focus on US postal workers only.

5.8 Policy Implications

In the following section, the most important policy implications and best practice recommendations for various disaster related situations that can be derived from the abovementioned papers have been summarized.

For natural disasters, the following outcomes were achieved. Astonishingly, Gupta and Shah (1997) [40] found that a moderate level of retrofitting is the cost-efficient mitigation strategy in a sample conducted in Los Angeles. Kappos and Dimitrakopoulos (2008) [50] underline the importance of retrofitting for moderate earthquakes. In Pisaniello and McKay (2007) [68] it has been shown, that through a very easily applicable formula the risk of private dam failure can be considerably reduced, through limited investment of the dam owner.

Fisher et al. (1995) [33] concluded that the building of new water storage capacity in arid regions is not always the most cost-effective alternative. Shih and ReVelle (1995) [77] remark that their model needs to be extended to longer as well as multiple droughts in order to evaluate the effects on water rationing policies in times of drought.

The importance of dense forests and forestation in mountainous areas has once more been underlined in Grêt-Regamey et al. (2007) [39], as it is a very effective tool to reduce avalanche risk.

In the field of technological disasters, the following implications can be derived. Srinivasa and Wilhelm (1997) [78] found that optimal deployment and composition of oil spill cleanup facilities is vital to guarantee timely response.
Karkazis and Boffey (1995) [52] underline the importance of the inclusion of indirect costs of pollution on the population in hazmat transportation models. Furthermore, in these models the use of GIS should further be enhanced, as stated in Iakovou (2001) [47] and better visualization tools should be developed, as stated in Dadkar et al. (2008) [26]. For hazmat transportation not only the routing but also the scheduling of these transports is crucial, as can be found in Carotenuto et al. (2007a) [16].

The models dealing with terrorism forms show the following results. The outcomes of the simulations of Pendergraft et al. (2004) [67] were used to develop the security resource requirements for about 80 airports in the USA. The optimal deployment of baggage screening systems increases overall security at airports, as can be found in Jacobson et al. (2005) [48].

When a bioterrorist attack occurs, an effective detection of the release may reduce the severity of the attack[515]. It has been found that in case of a bioterrorist attack the effectiveness of the mitigation strategy can be considerably increased by the accurate vaccination strategy, as can be found in Kress (2006) [54]. Furthermore, the inclusion of social interactions should further be enforced, as stated in Kress (2005) [55]. In Braithwaite et al. (2006) [13] it has been found that more lives can be saved by "allocating resources to improve the response after an attack than by allocating resources to facilitate earlier detection of an attack"[516].

Albores and Shaw (2005) [3] underline that in decontamination situations, the number of non-ambulant people should definitely be taken into consideration to optimize overall decontamination time via decontamination tents which exclusively deal with non-ambulant persons. The point of dispensing design models, as in Aaby et al. (2006) [1] and Whitworth (2006) [86], show how to effectively staff each station of the clinic and will further be enhanced in cooperation with public health officials and through further exercises which are

[515] Cp. [70] Reshetin and Regens (2003), p. 1144.
[516] [13] Braithwaite et al. (2006), p. 191.

conducted. Especially in the field of a potential bioterrorist attack the attack probability[517] and population exposure[518] might decisively influence the cost-effectiveness of the proposed measures.

It has been found in Kress (2006) [54] that a mass vaccination strategy is more effective than trace vaccination, but a prioritized vaccination policy, a mixture of the before mentioned, is the most effective strategy in case of a bioterrorist attack with smallpox.

Bottlenecks of the system have been found, as for example Patvivatsiri (2006) [66] has shown that the number of beds for medium-heavy and severely injured patients are the bottlenecks in the scenario of bioterrorism preparedness in ER. The transportation of critical patients creates a bottleneck in the simulation of Taaffe et al. (2006) [79], therefore it is crucial to use a high number of ambulances for hospital evacuation in the event of a hurricane. Not only the number of emergency resources is of importance but considerable improvements of the entire response process can be achieved through a more efficient location and allocation of these resources, as stated in Berman et al. (2007) [12], Friedrich et al. (2000) [35], Haight and Fried (2007) [42], and MacLellan and Martell (1996) [59].

General policy implications not focused on a specific disaster type are discussed below.
Evacuation models, as for example Bakuli and McGregor Smith (1996) [5] show the effect of resizing of emergency egress routing plans on the throughput; the necessity of sufficiently broad exits has to be kept in mind in the designing or redesigning process of buildings. This has also been confirmed by the findings of Chow and Ng (2008) [23].

Chen and Zhan (2008) [20] state that the appropriateness of an evacuation strategy strongly depends on the characteristics of the evacuated area, i.e., population density or the road network and therefore no overall valid optimal evacuation strategy can be announced. In an urban evacuation simulation it showed critical that adjacent urban areas should not be evacuated at the same time as this leads to an overcrowding of the evacuation routes[519]. Generally speaking, it is not optimal to evacuate a large area, as this slows down the

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[517] Cp. [34] Fowler et al. (2005), p. 608.
[518] Cp. [13] Braithwaite et al. (2006), p.182.
[519] Cp. [20] Chen and Zhan (2008), p. 25ff.

evacuation progress and in most cases there is not enough lead time to initiate such a large-scale evacuation[520].

The parameter resource utilization might further enhance the practicability of evacuation scenarios, as stated in Shendarkar et al. (2006) [74]. In Taaffe et al. (2006) [79] it has been underlined that evacuation models for no lead time disaster scenarios have to be taken into consideration in the future.

In general, Papamichail and French (1999) [65] conclude that the reduction of possible response strategies might considerably reduce the number of feasible alternatives and therefore render the decision making process after a disaster occurred less complex. Several authors state that more detailed data are required to extend existing models, as stated in Jacobson et al. (2005) [48], Chang et al. (2005) [19], and Vanem et al. (2008) [83].

Concluding, several authors such as Patvivatsiri (2006) [66] and Akgün et al. (2007) [2] state that a relaxation of some assumptions taken in the model might be helpful in order to simulate more realistic scenarios, sometimes the evaluation of a problem should be evaluated with the help of different analyses to avoid overhasty decisions, as has been underlined in Riddington et al. (2004) [71]. Furthermore, a combination of various strategies often shows to be preferable to only a single strategy, compare Jain and Davidson (2007) [49] and Miller et al. (2006) [61].

[520] Cp. [38] Georgiadou et al. (2007), p. 1394.

6 CONCLUSION

This thesis intended to demonstrate research directions in the field of disaster management in OR literature. An economic evaluation of disasters attempted to underline the necessity of effective disaster management, these guidelines of researchers should help disaster managers to make better decisions in emergencies. Moreover, the role of simulation in disaster management, disaster management in hospitals, and the role of insurance in this process were outlined shortly.

After the discussion of the literature and the classification of the respective disaster types, 90 papers were selected for deeper investigation. The criteria focused on in the reviewed articles form the framework for the dimensions of the taxonomy. The taxonomy attempted to give a deeper insight in relevant models and interventions discussed in the literature. Finally, policy implications and results summarized the main outcomes of the taxonomy.

There exists a very broad literature for the complex topic disaster management, therefore a thorough differentiation is indispensable. Although this work is not intended to give an all-embracing overview of disaster management literature, but rather illustrative main examples of the research directions of the last 25 years of disaster management literature, several conclusions can be drawn.

It has been found that most of the literature deals with mitigation, preparedness, and response activities; however, literature still faces a lack of developed recovery strategies for the long-term regeneration of the affected areas. Most research considers strategic decision making; only a few authors analyze the tactical or operational level.

The management of droughts is underrepresented in the OR related literature, probably because of the fact that the countries mostly affected by drought are developing countries and therefore less attention is paid them. Indirect costs are rarely taken into consideration as they are hard to assign and to evaluate. Moreover, limited data availability constrains the outcomes of the models and their applicability to real-world situations. In general, cooperation and coordination of the entities involved are crucial to guarantee timely and efficient assignment of scarce resources. Furthermore, different authors confirm that a combination of various measures often achieves a better outcome than if tools are used autonomously.

The above mentioned taxonomy has underlined that although there exists a vast disaster management literature dealing with various problems related to mitigation, preparedness, response and recovery from disasters, there are only a few authors evaluating the actions taken through economic analysis such cost-utility, cost-effectiveness, or cost-benefit analysis. The evaluation of interventions via effectiveness-related, resource-related and cost-related parameters is very common, still economic analyses in the narrower sense are underrepresented in the literature. This is astonishing as these tools can be used to compare different measures from an economical point of view and create a justification for the implementation of specific measures.

In the future, to be able to evaluate interventions, or to figure out the most effective intervention among several interventions, it is crucial to stronger rely on the abovementioned economic analyses. That way, the growing occurrence and intensity of disasters[521] can be tried to at least be partly absorbed due to more effective interventions taken.

[521] Cp. [290] CRED (2008), p. 11. [access on June 1st, 2008].

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VI. APPENDIX

ABSTRACT (ENGLISH)

This thesis intends to demonstrate current research directions in the field of disaster management in the Operational Research literature. Disaster management in this context comprises the management of natural, such as geophysical and hydro-meteorological, and technological disasters, such as industrial accidents, transportation accidents, and miscellaneous accidents, as well as the management of the different terrorism forms, general terrorism and bioterrorism. As the occurrence of disasters is getting more and more frequent and the accumulated loss of these events is getting higher and higher, there is a strong need for the development, implication and economic evaluation of strategies to counter these disasters.

In the first part of the thesis, a general overview of the literature is given, including a focus on simulation, disaster management in hospitals, and the role of insurances in the disaster management process. The second part encompasses the taxonomy which focuses on models and outcomes presented in the literature. As a result of the review of the literature, appropriate categories for the disaster management taxonomy are derived. On the one hand, an overview of general model features, i.e., the level of disaster management, model type and methods of application is given. On the other hand, the type of intervention used and the practicability for different disaster types are discussed. 90 papers, illustrative main examples of the research directions of the last 25 years, were selected for deeper investigation and classified according to the main criteria analyzed in the articles.

The main focus of the taxonomy lies on the economic analysis, which encompasses effectiveness-related, resource-related, and cost-related parameters and shows the type of economic analysis used in the literature. We analyze whether economic analysis, i.e., cost-utility, cost-effectiveness, and cost-benefit are used to investigate different interventions and what type of analysis has been chosen by the authors.

Policy implications and results show that considerable improvements can be achieved for different disastrous events and in different situations. Limited data availability constrains the outcomes of the models and their applicability to real-world situations. In general, cooperation and coordination of the entities involved are crucial to guarantee timely and

efficient assignment of scarce resources. Furthermore, different authors confirm that a combination of various measures often achieves a better outcome than if tools are used autonomously.

The taxonomy has underlined that although there exists a vast disaster management literature dealing with various problems related to mitigation, preparedness, response and recovery from disasters, there are only a few authors evaluating the actions taken through economic analyses such cost-utility, cost-effectiveness, or cost-benefit analysis.

In the future, to be able to evaluate interventions, or to figure out the most effective intervention among several interventions, it is crucial to stronger rely on the abovementioned economic analyses.

ABSTRACT (GERMAN)

Das Ziel dieser Arbeit ist es, aktuelle Forschungsschwerpunkte im Bereich des Katastrophenmanagements in der Operational Research Literatur aufzuzeigen. Katastrophenmanagement umfasst in diesem Zusammenhang einerseits Naturkatastrophen wie geophysikalische und hydro-meteorologische Katastrophen, technologische Katastrophen wie industrielle Unfälle, Transportunfälle und sonstige Unfälle, und andererseits die verschiedenen Formen des Terrorismus, allgemeinen Terrorismus sowie Bioterrorismus. Da die Anzahl und das Ausmaß von Katastrophen immer weiter zunehmen ist auch eine immer größere Notwendigkeit für die Entwicklung, den Einsatz und die wirtschaftliche Beurteilung der jeweiligen Strategien gegeben.

Der erste Teil dieser Arbeit gibt einen Überblick über die Literatur im Bereich des Katastrophenmanagements und umfasst Simulation, Katastrophenmanagement in Krankenhäusern und die Rolle von Versicherungen im Katastrophenmanagementprozess. Im zweiten Teil wird eine Taxonomie entwickelt, deren Kategorien auf den Modellen und Ergebnissen der Literatur beruhen. Einerseits werden allgemeine Modelleigenschaften wie die Ebene im Katastrophenmanagementprozess, der Modelltyp und die Anwendungsgebiete der Modelle untersucht. Andererseits stellen die Art der Intervention und die Anwendbarkeit für die unterschiedlichen Katastrophenklassen weitere Kategorien der Taxonomie dar. Es wurden 90 Artikel, die beispielhaft für die Forschungsrichtungen im Bereich des Katastrophenmanagements der letzten 25 Jahre stehen, ausgewählt, und entsprechend den jeweiligen Kategorien der Taxonomie zugeordnet.

Das Hauptaugenmerk der Taxonomie liegt auf der wirtschaftlichen Analyse, die wirksamkeitsbezogene, ressourcenbezogene und kostenbezogene Parameter umfasst. Es wird gezeigt ob und welche wirtschaftliche Analyse wie beispielsweise die Kosten-Nutzwert-Analyse, die Kosten-Wirksamkeits-Analyse und die Kosten-Nutzen-Analyse angewendet wird um die in den Artikeln beschriebenen Interventionen zu evaluieren.

Es wird gezeigt, dass erhebliche Verbesserungen für die verschiedenen Katastrophentypen und in den verschiedenen Situationen erzielt werden können. Eingeschränkte Datenverfügbarkeit schränkt in vielen Fällen die Einsetzbarkeit der Modelle in realen Situationen ein. Im Allgemeinen ist erkennbar, dass Kooperation und Koordination zwischen den beteiligten Einheiten ausschlaggebend für den zeitgerechten und effizienten Einsatz der

knappen Ressourcen sind. Oftmals erzielt der gemeinsame Einsatz mehrerer Maßnahme ein deutlich besseres Ergebnis als der Einsatz von lediglich einem einzigen Instrument.

Die Taxonomie unterstreicht dass trotz der großen Fülle an Literatur im Bereich des Katastrophenmanagements nur wenige Autoren auf die Kosten-Nutzwert-Analyse, die Kosten-Wirksamkeits-Analyse und die Kosten-Nutzen-Analyse als Hilfsmittel zur wirtschaftlichen Analyse zurückgreifen. In Zukunft, um Interventionen erfolgreich evaluieren zu können oder die beste aus mehreren Interventionen bestimmen zu können wird es immer wichtiger werden, diese Art von wirtschaftlichen Analysen anzuwenden.

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