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Decision-making and human behavior in emergencies with cascading effects

Deliverable Number:	D3.2
Date	April 15, 2016
Due Date (according to DoW)	June 30, 2015
Dissemination level	PU
Reviewed by	Xavier Criel, SCE

Grant Agreement No:	607665
Coordinator:	Anders Lönnermark at SP Sveriges Tekniska Forskningsinstitut (SP Technical Research Institute of Sweden)
Project acronym:	CascEff
Project title:	Modelling of dependencies and cascading effects for emergency management in crisis situations

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Executive Summary

This report deals with the issue of decision-making in emergencies with cascading effects. In order to examine this, information is taken from academic literature, interviews and case studies and analyzed with respect to the DoW. This includes data on response organizations in Sweden, The United Kingdom, Norway, Belgium, The Netherlands and France, research on several models of decision-making including associated social and organizational factors, case studies of the 2014 mudslide in Oso, USA, the 2005 bombings in London, UK and the 2014 forest fire in Västmanland, Sweden.

In order to support decision-making it is important to understand the nature of how decisions are made in a specific context. The aim of this report has primarily been to inform the modelling task of D3.1 and to give guidance to future developments of the IET. To these ends, several findings are presented that describe both issued that need to be taken into account and possible benefits of the IET.

A model of decision-making has to take into account that emergencies with cascading effects will involve many groups of actors such as responders, NGOs, political actors and the public. Findings from the literature and applied studies are used to construct a list of possible model characteristics and features, including factors that may hinder response effectiveness.

Moreover, a model of decision-making in emergency situations with cascading effects should reflect the fact that creating rationales for decision-making is a collaborative effort engaging many groups in a negotiation over information, decisions and actions. Creating this common ground for decision-making is particularly hard in the case of cascading effects because such emergencies likely involve groups that have little experience of working together.

This report has argued that the complexity of an emergency is largely dependent on the design of responding organizations and their procedures, support tools, training and other issues of management. Building a base for decisions is a process of situation assessment and lessons from field studies within the field of NDM indicate that first and foremost, technology should be used to support this situation awareness. Achieving this awareness could be more of a challenge in situations with cascading effects, because effects will carry over to domains that responders may not be as familiar with or have insights in. In this situation decision-making takes the form of negotiation. A tool such as the IET then has to be accepted as a valid, shared source of information in the larger collective of responders, and the information that it provides must be trusted by all stake-holders. On the other hand there will always be different interpretations of facts. Because nobody knows exactly what the future holds, different interpretations could be seen as a potential variability in decisions and actions, and this should be taken into account when designing the IET.

However, if a tool such as the IET is implemented in close collaboration with end users, it may serve to lower the perceived complexity of cascades in emergencies. In Appendix A, an applied study is presented of how evacuation modelling tools can be used to assist decision-making in case of emergencies with cascading effects.

With regard to key decision points in emergencies, it is argued reality will seldom allow enough predictability to generalize widely over such points, but that if key points are viewed as constructions within the operational context then efforts should primarily be made to support this construction, which means that the IET must also be able to act as a powerful operational tool.

1 Introduction

Decision-making in the emergency response context includes activities such as determining goals and needs, managing the costs of deciding, scanning the options, imagining consequences that are often non-obvious, conducting trade-offs and anticipating hindrances to implementation (Klein, 2015). Because of the dynamic nature of emergencies with cascading effects, decision-making during response operations is often marked by time pressure, complexity and uncertainty. The responders must work quickly to contain an evolving situation where information and resources may be scarce (Njå & Rake, 2009). Moreover, decision-making will often have to span several organizations, placing demands on effective coordination and collaboration (Kapucu & Garayev, 2011).

This report will explore the characteristics of decision-making under adverse circumstances where there is a risk for cascading effects. First a vision for the development of the IET will be presented. This will be followed by the work group's interpretation of the DoW for tasks 3.1 and 3.2. The first chapter of the report presents an overview of systems for emergency management in a number of European countries with a focus on decision-making strategies. In the following chapter a review is made of experimental research centered on the cognition of the individual as well as ecological models of decision-making. This will be followed by a chapter presenting three case studies where decision-making has been analyzed, both in relation to theory and to other aspects of decision-making in an emergency response context. Each chapter ends with an analysis where findings are interpreted in the light of the DoW. The aim of this report is to find key aspects of decision-making in emergency response where there is a risk of cascading effects. Results will form the base of the modelling task in D3.1, but there is also an ambition to use knowledge about decision-making and sociotechnical systems in other parts of CascEff, for example during the design and implementation of the IET.

2 Vision for the IET

Because the D3.1 and 3.2 reports are largely concerned with informing later stages in the development of the IET it is important to describe the current vision for the design and use of this tool. This vision will then be referred to under the different topics visited in the present report.

2.1 Vision

Information on possible cascading effects is needed during all stages of an incident: Planning, Preparation, Response and Recovery. Plans seldom survive, but planning is everything; flexible emergency response requires thorough preparations.

The IET should give information on cascading effects, both on originators and dependencies to identify key points in which the cascade could be broken, and on consequences which would serve the purpose of managing the recovery.

The IET could help to make information on cascading effects more objective, and support the alignment of the vision of different partners with different goals, different experience, different skills, etc.

The results from the IET should enable prioritization of decisions and resources.

The IET should not just be an additional tool. IET needs to be scalable and complement current systems. It shall also be useful for every-day purposes; otherwise it would not be used in exceptional situations either.

The IET should advise the user on potential scenarios, allow dynamic description and predict cause-effect chains. It should model and illustrate the linkages between systems. The IET should also help predicting risk in terms of secondary and tertiary effects.

By use of the IET it could be possible to reduce probability and consequence of cascading effects through proper risk planning and preparation. Cascading effects can be managed in advance by e.g. verifying existing plans, training exercises, and strengthening the safety culture.

As a result of the use of the IET in planning and preparation, following the identification of potential cascading effects proper capacity planning such as calling in pre-defined emergency management capabilities, involving pre-defined experts, verifying tactical assumptions, considering evacuation, etc. It is also recommended that when cascading effects are identified the following should be considered: collaboration with key actors, involvement of stakeholders and experts for advice, isolaton of the affected portion of the system, re-connecting the affected system in a controlled manner, expanding the command structure and enhanced reporting to the superiors.

In the response phase the main use of the IET can be to show the links between systems and the risk for cascading effects. It can visualize the probable paths of the incident and thereby also key points for decisions and intervention. The results can also enable prioritization of decisions and resources.

In the recovery (and post-incident) phase the IET should enable analysis and explanation of the cascading effects and thereby ensure that lessons are identified as well as learned and implemented.

3 Description of work

This chapter begins with a reproduction of the Description of Work (DoW) for tasks 3.1 and 3.2, followed by the work group's interpretation of the DoW and intentions toward the present report.

Task 3.1 Tactical first responder operations

Emergency management is comprised of both organizational and operational preparedness, to cope with emergency situations. This requires an understanding of resources, their tactical use and distribution.

The focus will be on the interaction between how first responder activities impacts on the event, and the impact of the event on the first responder activities. First responder activities which need to be taken into account and key points in the incident evolution, where decisions need to be made and what type of decisions in the crisis management chain that are needed will also be identified and addressed.

The research will develop scenario based models, which can take into account elements such as overall risk and vulnerability assessment covering an area of responsibility of first responders. The models should allow for the adaption of the operational structure of a service to the localization of vulnerabilities and risks as well as decisions on appropriate operational strategies and the level of preparedness, including determination of the localization of resources. The processes of triage will also be included.

This task will develop guidance to:

1) enhance first responders' understanding of and interaction with their operating environment through their use of the Incident Evolution Tool by the incident commander.

2) enable first responders to perform their duties safely and effectively, including proper resource allocation and use based on the output from the Incident Evolution Tool.

Based on Task 2.1, and in cooperation with WP2 (originators and dependencies), the role and effect of decisions and emergency management on the risk for cascading effects from an emerging incident will be identified.

Interagency and cross-border effects will be studied with regard to their effects on incidents and operations.

Task 3.2 Effect of human activities on the course of events

There are several different groups of people (general public, authorities, managers of infrastructure or business, etc.) in addition to first responders, that by various action (or decisions not to act) can affect the course of events. This task will study the effects on how the incident develops as a result of decisions made by, and activities of, other people than first responders in relation to the incident. The effect of such actions and decisions will be defined by studying previous incidents and the scenarios selected in this project. By studying previous incidents with cascading effects different groups of people will be identified and it will be analyzed how their decisions have an effect on the course of event for the studied incidents. The focus will be on identifying what kind of decisions that can occur at an incident with cascading effects, on which grounds the decisions are taken and how different decisions can affect the course of event in one direction or another.

3.1 Interpretation of the DoW

During a large-scale incident, first responders and other actors can be seen as parts of one socio-technical system that works to achieve several common goals. In this system, risks typically develop when several problems combine or when interactions between system functions are disturbed. Because of the tight interactions between first responders, the environment and other actors such as NGOs, volunteers and the general public, the decision was made to deal with the all decision-making related topics in the present report. The report for D3.1 will contain descriptions of the rationale and design of the flowchart for first responder decision-making as well as the flowchart itself.

The present report will examine how decision-making and interactions flow in the response to events with cascading effects. This will be carried out from the perspective of socio-technical systems, where decision-making occurs as a process distributed among several actors, environments and tools. To accomplish this, decision-making will be described using several sources – both basic and applied research, information on national systems for emergency management, case studies on incidents with cascading effects and knowledge about work modelling.

The aim of the report is to describe decision-making as a situated, distributed activity interwoven with other activities. Different components or attributes of decision-making will be examined such as decision typologies, the existence of key decision points, decision rationales, decision outcomes with regard to cascading effects, physical locations for decision-making and finally, the impact on decision-making by actors outside of the first responder organizations.

In the study of first responder activities, special interest will be directed toward issues of prioritization, dissemination of information with issues of responsibility, information

dissemination, reporting structures and the allocation, use and distribution of resources. In this context “resource” is interpreted in a wide scope as capabilities, referring to both physical assets and resources such as personnel and competencies. When operational response work is examined, special attention will be given to organizational issues such as interagency and cross-border effects.

The end product of these two reports is a flowchart describing first responder decision-making, taking into account the functions, activities, resources and performance-shaping factors identified in the present report. The purpose of this flowchart is primarily to aid in the demonstration of possible uses of the IET which in turn will aid first responder decision-making. However, it is also possible that the flowchart could be used directly, e.g. for discussions around risks and vulnerabilities, first responder strategies and tactics. The information gathered around decision-making in this report will lend itself to many purposes within CascEff, for example by informing the design and implementation of the IET.

4 Organizational and operational preparedness

Emergency management is comprised of both organisational and operational preparedness, to cope with emergency situations. These kinds of preparations require an understanding of resources, their tactical use and distribution. Chapter 4 is a mixture of theoretical framework and descriptions of how these aims are practically implemented by first responder organizations in Sweden, United Kingdom, Belgium, France and the Netherlands.

4.1 Organizational structure of the Swedish system

The text in sub section 4.1 is to a large degree based on a more comprehensive CascEff report (Svensson, 2015).

An important basis for the Swedish parliamentarianism is local self-government, which has a large impact on first responder activities. Local self-government means that local authorities take care of local or regional issues and they have a very wide discretion (Local government act, 1991:900). In short: the government doesn’t generally interfere with local matters.

In Sweden today there are 290 municipalities and 20 counties. The former's responsibilities include in Sweden local issues (in other countries, responsibility can be divided differently between different types of municipalities and the state) as spatial planning, infrastructure, housing and business development, and welfare services such as schools, elderly care and health care. The mission of the municipalities is generally since 1862 to manage its "internal matters of common concern" and developing and operating a well-functioning society at local and regional level, with citizen participation and accountability of elected representatives. The county council care health and to some extent traffic and business development.

Consequently, local self-government has an impact on first responder activities. There are safety regulations as well as a few general requirements municipalities have to fulfill (Civil protection act, 2003:778; Civil protection regulation, 2003:789; AFS 2007:7). This includes responsibility to have an organization with ability to respond to accidents and incidents, and requirements on responsibilities for incident commanders. But, and this is an important aspect of local self-government, there are not really any regulations or requirements on staffing, response time, equipment (apart from more general safety aspects). Each and every municipality may organize and equip their rescue service as they please, although the impact through training, inter-municipal cooperation, history and traditions is large. Therefore, there

are more similarities than differences as a national overall when it comes to how the rescue service works at accidents.

In terms of first responders, the municipal rescue services consist of the fire service. In the counties, the rescue services mainly consist of the emergency medical services and on a national level it is the police who are first responders, although these regional and national organizations act locally. Each actor/authority has staff trained to meet the organization's mission (again, from a legal point of view). No organization has the right to give directives over the others, which is a consequence of the local self-government system. But, in most cases it requires several different skills to assess an event and act so that the need for assistance is handled effectively. Therefore, responding actors identify the need for assistance together and design their various actions as a whole (Fredholm & Göransson, 2006). One can say that the responding agencies set the scene for each other. However, it requires each operator to be able to see the situation from a holistic perspective. Consequently, situations requiring flexibility, foresight, quick decisions and fast action can be difficult to handle, especially when several authorities are involved. In most cases the fire services are the first responders on the scene and in most cases the incident commander of the event is from the fire services. Therefore the continued work in this chapter focuses on the fire service, although the cooperation between fire services, police and emergency medical services is natural from the perspective of first responders.

4.1.1 Basic principles for fire services

The municipal organization for fire and rescue operations is the part of society's help in accidents that the public knows best, often in terms of the fire service. The fire service has a very good reputation among the public (SKL, 2014) and the vast majority expect, rightly, that the fire service will provide assistance in case of emergencies. Often, the fire service has local roots, with a history linked to the people living in smaller towns and villages. In old days, it was a duty for everyone in the village to assist in case of fires or other emergencies (Brandsjö, 1986).

The fire service is only obligated to intervene if the individual himself does not have sufficient resources to cope with the situation when an accident has occurred (civil protection act 2003:778, Government bill 2002/03:119). That the municipality has a certain readiness to deal with accidents does not deprive individuals of their responsibilities. The fire service is obliged to intervene when an accident occurs or when imminent danger of an accident exists if the following key-points are fulfilled; having regard to the need for rapid intervention, it threatened interests, costs of an operation and other circumstances is necessary that the municipality is responsible for the operation. The municipality is thus required to have an appropriate organization, the fire service.

A municipality shall also have a program for their fire and rescue activities, where the general public can take part of how the fire service is organized, its resources, response time to different areas and the level of protection provided by the municipality, with regard to expected or possible scenarios leading to fire and rescue operations (2003:778).

A fire service organization is mainly based on line organizations and a hierarchical approach to management, although the work at an accident site in many cases requires a high degree of flexibility. In a line organization, authority flows from top to bottom and accountability goes upwards from the bottom along the chain of command. In some cases, management is supported by a staff and one can speak of a line staff organization. In such an organization emphasizes is on the team's overall specialist role, the staff is a provider of data for the

manager's decision and that the team consists of experts available to the department's disposal.

4.1.2 Large scale event management

In case a large scale event (which in Sweden is called extraordinary event), defined as an event that deviates from the norm, implies a serious disturbance or imminent risk of a serious disturbance in important societal functions and requires urgent action by a municipality or a county council, a crisis management committee should be established (Act 2006:544). Such a committee may decide to take over all or part of areas of activity from other committees in the municipality or county council to the extent that is necessary in view of the extraordinary event's type and scope. An extraordinary event may affect in such a way that resources becomes limited and therefore possibly a more thorough assessment decisions should be made about which type of incidents (based on size, characteristics, geographical area etc.) should be responded to.

The Swedish emergency management preparedness is based on society's normal, daily activities to prevent and handle accidents and less extensive disorders. In case of serious incidents or crises in society, resources can be strengthened. Emergency preparedness is thus the capacity created in many actors' daily business and not a designated organization or an actor (www.msb.se).

The Government bill (2005/06) – "*cooperation in crisis – for a more secure society*" state that the basic principles for the society emergency preparedness are:

- **Responsibility** – an organization that has responsibility for operations in normal situations also have a similar responsibility during a crisis or societal disruption. Actors affected by such an event, direct or indirect, that can help to deal with consequences have a responsibility to act also during a crisis. Consequently, actors should support and cooperate with each other.
- **Proximity** - that social disorders should be managed where they occur, of those who are most affected and responsible, at a as low hierarchical level as possible.
- **Equality** - actors should not make major changes in their organization other than needs inflicted by the event. Operations during events will function as during normal conditions, as far as possible.
- **Geographical area** - responsibility to ensure coordination between all those involved in emergency preparedness at local, regional and central level. Municipalities have the geographical area of responsibility within their geographical area, county councils within the geographical area of the county and government for the entire country.
- **Sector accountability** - the responsibility of government authorities for their issues of national matter, regardless of geographic extension.

4.1.3 Emergency management process

The command and control structure in the Swedish fire and rescue service has to a large extent been influenced by the viable systems model (Beer, 1972), adapted and implemented by Cedergårdh & Wennström (1998) further developed, adapted and implemented by Svensson et al. (2009). The viable system model (VSM) expresses a model for a viable system; any system organized in such a way as to meet the demands of surviving in a changing

environment is a viable system. One of the prime features of systems that survive is that they are adaptable.

According to VSM, a viable system is composed of five interacting subsystems (Beer, 1972). Generally, systems 1–3 are concerned with the 'here and now' of the organization's operations, System 4 is concerned with the 'there and then', which are the strategic responses to the effects of external, environmental and future demands on the organization. System 5 is concerned with balancing the 'here and now' and the 'there and then' to give policy directives which maintain the organization as a viable entity. In addition to the subsystems, the environment is represented in the model. The presence of the environment in the model is necessary as the domain of action of the system and without it there is no way in the model to contextualize or ground the internal interactions of the organization.

Overall, the command and control system in the Swedish fire and rescue service is considered to be a viable system, able to meet the demands of adapting in a changing environment. This is based on fairly well trained and experienced firefighters and incident commanders.

The command system (see Figure 4.1) is based on several parts, where the affected context describes and consists of those parts of society where a need for help arises due to an event, and the operational context describes and defines actors who should cooperate and coordinate their activities during response. In the command system used, three levels are identified: to execute tasks, to execute operations and to provide municipal rescue service. To each of these levels a decision domain is linked; system command, operation command and task command, which describes and defines a set of decisions that can be inflicted by the command level and thus affects its surroundings.

In the model, the decision domain task command is a subset of the decision domain operation command which in turn is a subset of the decision domain system command. The decision domain system command comprises all the other decision domains so that the model becomes a coherent system of interactions between the distributed decision-making, where system command is tied to the overall responsibility.

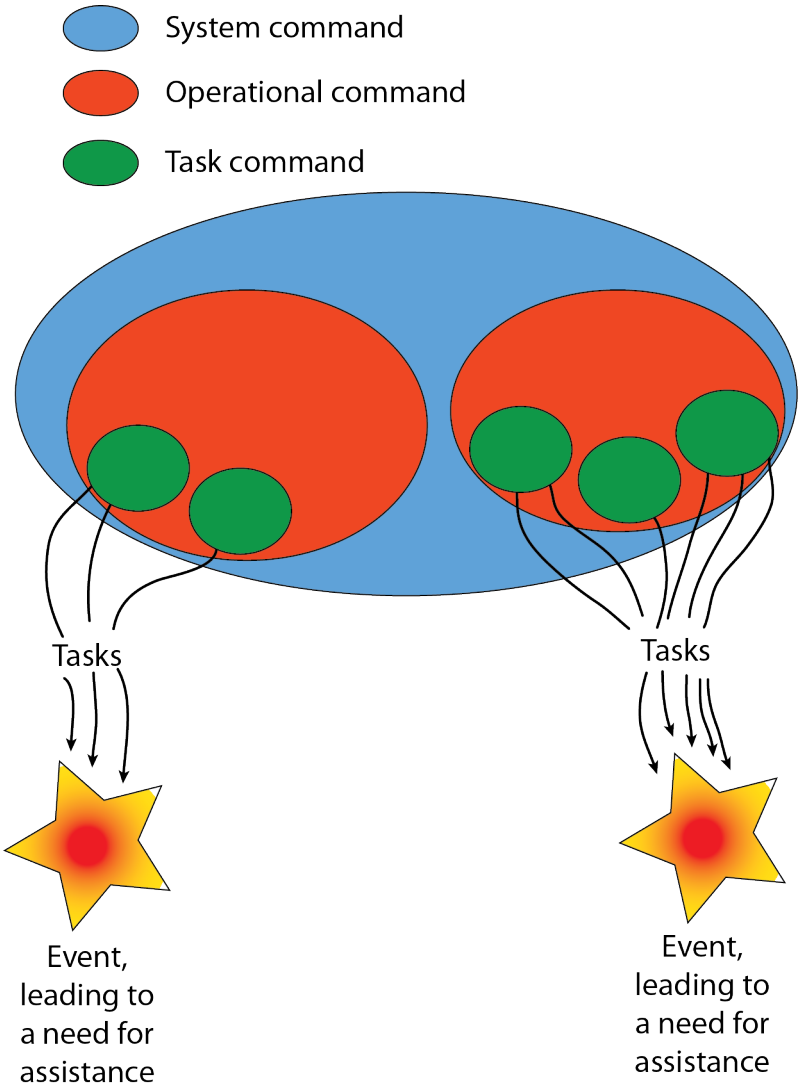

Figure 4.1 Decision domains in the command system (Svensson et al., 2009).

The decision domain *system command* defines the role of the organization, in relation to other organizations involved in the event, it defines the framework for operations (in terms of intentions of operations, resources, geography), it provides resources over time and it manages preparedness in relation to the overall level of risk. This decision domain is the overall command function, responsible for the organization.

The decision domain *incident command* determines objectives for an operation, decides and assigns tasks to units involved in an operation and coordinates an operation. In most cases, the role of an incident commander is linked to the decision domain operation command. This decision domain is linked to individual operations and, consequently, there can be several such decision domains in case there are several ongoing operations.

The decision domain *task command* manages units in their execution of assigned tasks and coordinates the effort to fulfill those tasks. In most cases, there are several decisions domains task command within a single operation.

4.1.3.1 Incident commander

According to Swedish law (2003:778) there must be an incident commander at any rescue operation. The purpose of having an appointed (and competent) incident commander is of course to effectively and safely manage and carry out operations. Since the obligations and responsibilities that come with the role of incident commander involve restrictions on civil rights and liberties, these must be addressed consistently and based on informed judgments. These obligations and responsibilities include (2003:778)

- To initiate and end rescue operation
- Interference with the rights of others
- Request of duty by civilians to serve
- Conduct surveillance at the expense of others
- Request assistance of other authority, and to
- Notify the authority responsible for defects or irregularities that could lead to other emergencies.

Incident commanders must of course not make decisions on these issues arbitrarily or by tradition: each decision must be substantiated and assessed against a specific situation. The decision must be necessary and the action or actions leading to the decision must outweigh the intrusion on the individual. It cannot be emphasized enough that these duties and powers are severe restrictions on civil rights and liberties, and they must be handled with care. They therefore place also fairly high demands on the skills of the individual who is the incident commander.

These specific decisions must be reported in writing. The decision must specify when and by whom the decision is taken and the reasons for the decision and to whom it relates. If the incident commander is not at the scene in person, which is fully legitimate, but for example in a command center, there are high demands on good, thoughtful and informed decision-making including effective and clear communication between incident commander and on-scene commander.

The obligations and responsibilities related to the role of an incident commander is further developed and described below.

4.1.3.2 Strategic coordination

Because the Swedish emergency preparedness is based on the three basic principle *responsibility, proximity* and *equality*; the ability to manage emergency response is created in the daily business work and are not a special organization or actor. Thus in case of an extraordinary event that put a lot of strength on the society; municipalities or county have the geographical area of responsibility at the local level, which means that they will work to ensure cooperation and coordination between actors within the community before, during and after the extraordinary events. The task is also to coordinate information to the public during such events. Municipalities and counties also owns and operates important functions (such as; water distribution, electricity, rescue service, infrastructure etc.) that must serve either not to fall into crises, or to manage crises when they occur. In order to fulfill their duties a municipality or a county council, can establish a crises management committee (Act 2006:544) that can take over functions from other committees in the municipality or county to the extent that is necessary in view of the extraordinary event's type and scope. The committee is responsible for strategic coordination and cooperation and is the highest authority in the municipality or county during the event. The committee often has a team who assist them and

depending on the event the team consists of experts and representatives considered valuable for the management of the event. (www.msb.se)

4.1.4 Labour management rights and health and safety responsibilities

The health and safety responsibilities include an obligation to be active and take action by eliminating or reducing the risk of illness and accidents at work so that the working environment is good. This can have an impact on decision-making. An employer must allocate the tasks in the organization in such a way that one or more managers, supervisors or other employees are tasked to ensure that risks at work are prevented and a satisfactory working environment is achieved. The employer must ensure that those who receive these data are sufficient and have the powers and resources needed. The employer must also ensure that they have sufficient knowledge of rules relevant to the work environment, physical, psychological and social conditions implying risks of illness and accidents, measures to prevent illness and accidents, and working conditions conducive to a satisfactory working environment (Arbetsmiljöverket, 2012).

It is a responsibility of the senior management in an organization to distribute task related to health and safety issues, in most cases to officers in the organization. These can in turn distribute such tasks if they have such rights to their respective managers. However, the senior management always has an obligation to regularly monitor the task allocation so that this works in practice and, if necessary, make any changes necessary.

Consequently, labor management rights as well as health and safety responsibilities have a large impact on the work during operation. An officer can make decisions on what their personal should do, but the personal are entitled to refuse to fulfill tasks given. For many years, there has been a very strong focus on the incident commander. However, the obligations and responsibilities that come with the role of incident commander is much less important than labor management rights and health and safety responsibilities, which has a much larger impact on an operation.

4.2 Organizational structure in the United Kingdom

The Civil Contingencies Secretariat (CCS) is the department of the British Cabinet office responsible for emergency planning in the UK. They have written guidance accompanying the Civil Contingencies Act (2004) with focused on to get a shared understanding of the emergency response for all level (from local to national) and organizations. The aim of the guidance is also to have a common frame for concepts and language for all organizations that are involved in emergency response. Appendix A in the guidance provide an overview of the Civil Contingencies Act 2004 that explain the basic principle of those involved in emergency response (CCS, 2013), see below:

Part 1 of the Act and the supporting Regulations, and the statutory guidance Emergency Preparedness, establish a clear set of roles and responsibilities for those involved in emergency preparation and response at the local level. This helps to deliver greater consistency of civil protection activity at the local level; facilitate more systematic co-operation between responders; and lay the foundation for robust performance management.

The Act divides local responders into two categories, imposing a different set of duties on each. Category 1 responders are those organisations at the core of emergency response (e.g. emergency services, local authorities, NHS bodies). Category 1 responders are subject to the full set of civil protection duties. They are required to:

- assess the risk of emergencies occurring and use this to inform emergency planning and business continuity planning;
- put in place emergency plans;
- put in place business continuity plans;
- put in place arrangements to make information available to the public about civil protection matters and maintain arrangements to warn, inform and advise the public in the event of an emergency;
- share information with other local responders to enhance co-ordination;
- co-operate with other local responders to enhance co-ordination and efficiency; and
- provide advice and assistance to businesses and voluntary organisations about business continuity management (local authorities only).

Category 2 responders (e.g. Health and Safety Executive, transport and utility companies) are - co-operating bodies, which are less likely to be involved in the heart of planning work but will be heavily involved in incidents that affect their sector. Category 2 responders have a lesser set of duties – co-operating and sharing relevant information with other Category 1 and 2 responders.

4.2.1 Large scale event management

The Government's intention is to build up resilience across all parts of the UK. They use a framework called "National Resilience Capabilities Programme" aiming to ensure a robust infrastructure of response is in place to deal rapidly, effectively and flexibly with the consequences of a wide range of emergencies. The programme is divided in three groups; structural, essential services and functional and consist of total 22 active work-streams. Each work-stream has a designated lead Department. Within each work-stream the levels of capability of response to emergencies is monitored. The result is then used to rank UK's preparedness to emergency response. Further details on this programme and the role of each Government Department can be found on: https://www.gov.uk/preparation-and-planning-for-emergencies-the-capabilities-programme

4.2.2 Emergency management process

All category 1 responders must have emergency plans that include the procedure of determining if an emergency has occurred or not. Before only the emergency services made emergency plans but now this is something all category 1 responders can do. UK has a nationally management framework for emergency planning that will help to integrate emergency plans and procedures within and between agencies and across geographical boundaries. Following this framework will also aid different agencies during a combined response with understanding of their roles and responsibilities. Command, control and co-ordination are the three terms that the framework is based on.

The framework also refers to the difference between the functions of single and multi-agency groups. Where single agency has the right to command over their own personnel and asset; multi-agency role are to co-ordinate the involved agencies' activities, but not command. Multi-agency can, when appropriate, outline strategy for the response as a whole but it is expected that all involved agencies will work together and co-ordinated.

Emergency responders often refer to three levels of command:

Operational – the direct, hands on work undertaken on the site.

Tactical – co-ordinate different actions taken on the operational level.

Strategic – consider the wider context of the emergency, define and communicate the central strategy and objective for the response.

Single agencies often refer to the above level as bronze, silver and gold (CCS, 2013)

4.2.2.1 Disciplines involved in emergency response

In UK the bodies that are likely to be the core response to most emergencies is called category 1 responders. These responders most follow the full range of duties in Civil Contingencies Act, 2004 (CCS, 2013).

Table 4.1 Table of different category 1 responders in UK (CCS, 2013)

Responder	Tasks/responsibilities
Police	- Co-ordinate the activities of those responding to an emergency event (excepting when there is major fire) - Oversee any criminal investigation - Establish cordon - Co-ordinate search activities after survivors or casualties
Fire and rescue	- Co-ordinate activities on a fire scene - Extinguish and controlling fire and rescue anyone trapped by fire - Dealing with chemicals and other contaminants - Assist when flooding occur - Assist ambulance service with casualty-handling
Health bodies	For example: - Ambulance – Identify receiving hospital(s) and transportation, prioritisation of emergency treatment at the scene. - Acute trust and foundation trust – Provide general support and specialist healthcare to casualties at the scene. - Primary and community care services - Public Health England – identifies and responds to health hazards and emergencies caused by infectious disease etc.
Maritime and coastguard agency	- Initiate and co-ordinate civil maritime search and rescue at sea or shoreline
Environment agency	- Protecting and improving the environment
Local Authorities	- Wide range of functions that will probably be involved when an emergency occur.

4.2.2.2 The JESIP programme

The JESIP programme (www.jesip.org.uk) is a new (2012) and important way of thinking when it comes to better performance of the first responders at an incident. JESIP will have impact on over 100 organizations. The work in JESIP has ambitious goals and will also plan for the future by leaving a legacy and supporting structure. This is to ensure there are continuous improvements in how police, fire and ambulance services train and exercise together to save more lives.

The objectives for the JESIP programme are:

- To establish joint interoperability principles and ways of working (Joint doctrine, 2013)
- To develop greater understanding of roles, responsibilities and capabilities amongst tri-service responders
- To improve communication, information sharing and mobilization procedures between services including their control rooms
- To implement a training strategy for all levels of command
- To implement a joint testing and exercising strategy for all levels of command to ensure lessons identified progress into learning and procedural change

4.3 Organizational structure of the Norwegian system

Norway is now on the threshold of major changes in the emergency response services. There will be less but larger organizations and that the number to police – 112 and fire – 110 shall be co-located. The Government has just given the Directorate for emergency planning (DSB) the commission to reorganize the fire and rescue services according to the analyze report (called Brannstudien – or Fire Study) that was put forward in late 2013. The Government has decided that there should be larger and fewer fire and rescue services, and that in the future the fire and rescue services should be more focused on building professional competence environments.

A lot of ongoing reconstruction work on the emergency services and concepts follows the lessons learned from the 2011 July 22nd terror attacks. One of the changes that are quite new is a standard procedure for the police, health and fire on how to cooperate if there is a situation where violence that could lead to death of persons is taking place. The procedure is combined with obligatory standards on exercise and practice. There will be special trained instructors from the three focused services and the training and exercise should take place on a local and regional basis (Hans Kristian Madsen, 2015).

4.3.1 Emergency management process

From a Norwegian perspective (Hans Kristian Madsen, 2015) there are various models on how to be organized at an incident. There are more or less three main models:

1. Rescue operations when peoples life and health are at risk – characterized as follows:
    a. A joint operation, in most cases conducted by response units from the police, the fire service and the ambulance service (included air rescue ambulance).
    b. The mentioned services may be supported by other capacities. This could be resources from the Royal Norwegian Navy / Air Force / Army, NGO's (as The Red Cross and USAR-elements), Civil Defense Force, private contractors (such as salvage companies), Coastal Authority, Maritime Radio, Air Control Service as well as various volunteer elements.
    c. It is always a police coordinated operation, and it is strictly coordinated as long as the operation is about saving people in an emergency situation.
    d. All operations should be handled on the lowest possible level – but may expand to keep the span of control on a manageable level. The lowest level may be described as Sub Rescue Coordination Centre (SRCC). The Police Commander decides when SRCC is established, it may be only police personnel present, or police personnel joined by different services commanding officers at the Police Coordination Centre.
    e. On top – highest level - is the Joint Rescue Coordination Centre – there are two of those in Norway – Centre South in the city of Stavanger and Centre

North in the city of Bodoe (Bodø). The regional police chief – or Chief Constable chairs both the JRCC's Joint Rescue Boards.

f. Especially for these operations is that all public agencies involved cover their own expenses. NGO's and private contractors get their expenses covered by the Norwegian Government.
g. As soon as people's life and health no longer are at risk, operations is shut down, and recovery phase to be handled by the different responsible sectors.

2. Acute Pollution – characterized as follows:
    a. The concept is used only when accidents like oil spill and other hazardous materials are spilled. Focus is on protecting the environment.
    b. There are four phases of response. First, the agency or company responsible for the spill intervenes. Second, the local municipality takes action. Third, if the spill is on a large scale the regional intermunicipality organization take action. Fourth, if the situation is massive or it seems likely that it can evolve, the state pollution control authority shall convene the governmental action control group which task is to coordinate the response.
    c. All activities are stated in the Pollution Control Act.
    d. The local Fire and Rescue Services handles most of the operations on behalf of the municipalities.
    e. The Government covers for the municipalities expenses – only with a reduction of the municipality's own risk.

3. Any other incidents - characterized as follows:
    a. It is up to the local municipality to plan, prepare and act concerning other type of incidents as mentioned in the two other paragraphs above. This could be flooding, landslide and forest and bush fires. The list is not complete or exhaustive.
    b. It is up to the local municipality to prepare for intervention in these cases. The municipalities are obliged to carry out a risk and vulnerability analysis and plan and prepare for emergencies in a short- and long term perspective.
    c. Different response units and agencies may support the local municipalities. The municipalities have a wide range of services that may be put into risk reduction or reduction of consequences.
    d. The County Governor will support the municipalities as well as conduct surveillance on how they fulfill their obligations according to the Civil Preparedness Act. If several municipalities are affected by an incident, for example a flooding situation, the County Governor may coordinate the response for the affected region. There will always be close contact with other authorities such as the regional police district. If or until operations are fully conducted, the police are obliged to have command and control.

In addition to the three concepts listed above the Police have their command and control system quite similar to a military concept. The municipal and intermunicipal Fire and Rescue Services are currently implementing a Norwegian version of the Incident Command System (ICS). Three Norwegian authorities have together made a Norwegian version of the ICS concept. The system is in Norwegian named ELS (Enhetlig ledelsessystem) suited for all Fire and Rescue Services operations. The Civil Defense Force also adopts the ELS.

4.4 Organizational structure of the Belgian system

In Belgium, a clear distinction is made between daily relief and rescue operations and emergency management of large scale events. For daily relief and rescue operations, every discipline involved has its own framework (see table 4.1). Regulations provide for minimal obligations, complemented by operational practices. Both are learnt by training, education and exercises. This is the case for fire services, for police and services of urgent medical care, the three main operational disciplines involved. Each of these disciplines can arrive at the scene as first responders. It is not necessarily always the fire service.

Training and education teaches relief workers what they are expected to do and how to perform. What they have to do is based on their legal assignment and includes all types of activities to be able to assure their mission. Operational practices teach them how to perform them.

Recent reforms for police and fire services aimed at making the services more efficient. Police and fire service reforms had a few basic principles in common:

- Both reforms, for police (1998-2002) and fire services (2007-2015) introduced a scaling up, by creating zonal services, integrating several previously municipal services. The main purpose of this reorganisation was to work more cost-efficiently and more qualitatively.
- They both emphasize the need for a more integrated approach, looking for synergies with other services or with other public and partners in order to work more efficiently. One of the basic concepts for policy is 'integral security', fire services are obliged to work according to the safety cycle, which places their core business, interventions, in the middle of a continuous loop, covering proaction, prevention, preparation, intervention and evaluation.
- Both reforms introduced internationally accepted principles of quality management and risk management.

The so-called Safety Cycle which applies to operations of civil security is shown in Figure 3.2.

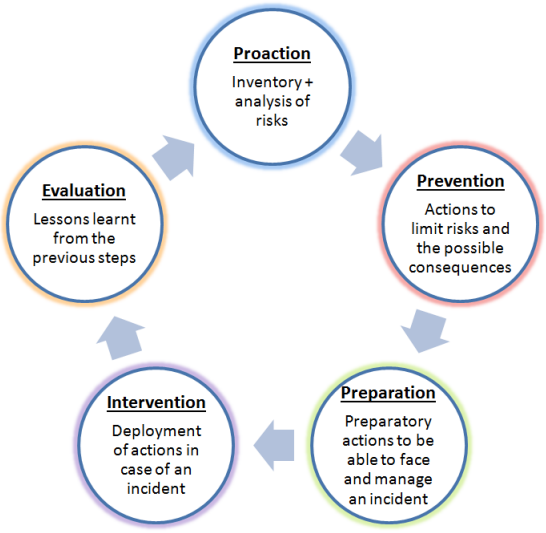

Figure 4.2 The so-called Safety Cycle which applies to operations of civil security (art. 11, §2 Law Civil Security 2007).

Fire services might not always be the first responders on the scene, but in most cases they are. And when other disciplines get involved, they are in most cases the operational coordinating body. For this reason, hereafter it is only the basic principles for the fire and rescue services that are explained.

4.4.1 Basic principles for fire and rescue services

As mentioned, the legal framework imposes only minimal obligations. With the recent reorganisation of the fire and rescue services, some new obligations have become key activities for qualitative interventions, such as:

- The obligation to conduct risk analysis. The results of these analyses serve as the basis for a pluri-annual policy plan, which mandatory has to cover the required material and human resources in order to be able to protect the zonal territory. Preparation is considered a key activity for qualitative interventions and it all starts with risk analysis. (art. 2, §1, 6°; art. 5 Law Civil Security 2007; RD Risk Analysis 2013)
- Interventions used to be territorially limited to the circumscription of the municipality. With the evolution to a zonal organisation, a new concept was introduced: 'Fast Adequate Intervention' abandons the territorial principles: it is the service who can provide the fastest adequate response who is called upon intervention. (art. 2, §1, 5°; art. 6 Law Civil Security 2007; RD Fast Adequate Response 2012)

4.4.2 Large scale event management

In Belgium a legal basis was created in 2003, completed by Royal Decree in 2006, in order to provide for a single framework for large scale emergency management, requiring a coordination of operations.

- In 2003, a legal provision was inserted in the Law on Civil Security (1963/2007), obliging the Mayor, the Governor and the Ministry of Interior to elaborate emergency plans at resp. municipal, provincial and federal level, in order to be prepared for multidisciplinary relief and rescue interventions.
- In 2006, a Royal Decree was issued, providing for minimal obligations:
    - A definition of emergency situation, which defines the scope of application of all the other legal provisions
        - A description of the tasks and responsibilities of the 5 functional disciplines involved in emergency management
        - The minimal content of emergency plans
        - The phases of emergency management and corresponding responsibilities
        - 2 coordination structures to be established in case of an emergency situation: one for strategic coordination – the Coordination Committee, and one for operational coordination – the Command Post Operations
        - 2 permanent structures: the uniform calling center or dispatch, the municipal/provincial safety unit
        - Organization of the intervention zone in case of emergency situations (exclusion, isolation and avoidance perimeter)

In Belgium emergency management with (possible) cascading effects requires per definition an interagency cooperation and coordination.

Large scale emergency management in Belgium is called emergency/crisis management. The RD 2006 defines an emergency situation as: *"every event that causes or could cause a damaging impact on society (such as a serious disturbance of public safety/security, a serious threat to live or the human health or to important material assets) requiring the coordination of disciplines to eliminate the threat or to limit the damaging consequences."*

Whenever this definition applies: the 5 disciplines are involved, according to the scale of the event a municipal, provincial or federal phase is declared, the 2 coordination structures are put in place, emergency plans should be elaborated for foreseeable scenarios (based on a risk analysis) and the arrangements/actions/measures described in the emergency plans are executed when an emergency situation occurs.

From the definition follows that the two main criteria for an emergency situation are 1) the (threat or potentially) damaging impact on society and 2) the need for coordinated action of the disciplines involved.

4.4.2.1 Disciplines involved in large scale event management

A discipline refers to a functional set of tasks/assignments. The services and organizations performing those tasks are either named in the RD 2006 or mentioned in the monodisciplinary relief and intervention plans. Different disciplines are described in Table 3.1.

Table 4.2 Table of different disciplines in the Belgium system.

Discipline	Tasks/responsibilities	Organizations involved	Led by
1 	Relief and rescue operations - management of the emergency situation, eliminating risks - saving and securing people and property - requisition of staff and equipment …	- Fire services - Operational units of civil security	Dir-Bw Highest ranked officer on the scene
2 	Medical, sanitary and psycho-social relief - establishing the medical chain - providing medical and psychological care - measures to protect public health …	- Services and organizations for urgent medical care - Organizations mentioned in the monodisciplinary emergency plan for discipline 2	Federal health inspector (strategic) + **Dir-Med** (appointed)

3		Police - maintaining and restoring public order - securing access and evacuation roads - evacuation of the population …	Federal and local police forces	Dir-Pol (cf. police regulations)
4		Logistic support - reinforcement of staff, material, specialized relief and rescue equipment - technical communication equipment - provisioning of food and water …	- Operational units of civil protection - Fire and rescue services - Specialized public and private services	Dir-Log Highest ranked officer of civil protection
5		Information - information/communication during and after an emergency situation - information to the public and media	The competent authority (Mayor, Governor, Minister), who appoints a Dir-Info	Mayor, Governor, Minister + Dir-Info

4.4.3 Emergency management process

The terminology Gold, Silver, Bronze for strategic, tactical and operational command is not commonly used in Belgium. Table 3.2 describes the corresponding levels of command in Belgium.

Table 4.3 Levels of command in Belgium.

Levels of command		BE terminology	Corresponding responsible body	Presided /led by	Location
Gold	Strategical	Strategical coordination	Coordination Committee	Mayor or Governor or Minister	Determined in the emergency plans
Silver	Tactical	Operational coordination	Command Post Operations CP-Ops	Director appointed (function of the type of emergency)	On site/on the scene
Bronze	Operational	Operational execution	The 5 (functional) Disciplines	Officer or doctor or civil servant in charge	On site/on the scene

Each discipline involved in emergency management keeps its own command and control structure and follows its own internal decision-making model.

As coordination is a key function in a multidisciplinary environment, 2 specific coordination structures are mandatory.

4.4.3.1 Strategic coordination

The competent authority is responsible for strategic coordination (RD 2006 Emergency Planning; FPS Interior, 2013).

The Coordination Committee is the multidisciplinary unit which assists the competent authority. The municipal Coordination Committee is composed of (minimal composition):

- A representative of each discipline, appointed by the discipline
- The civil servant responsible for emergency planning

The provincial Coordination Committee is completed with the Mayors of all the municipalities concerned, see Figure 3.3 and Figure 3.4.

Experts and representatives from organizations considered valuable for the management of the situation can be summoned by the competent authority to participate in the Coordination Committee.

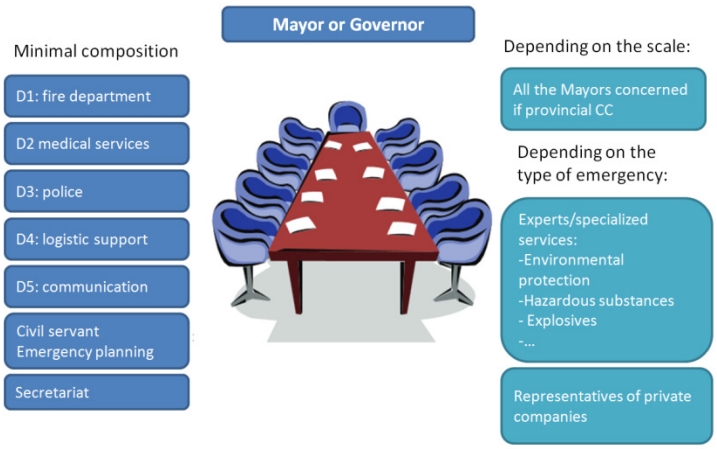

Figure 4.3 The municipal or provincial Coordination Committee (FPS, 2013).

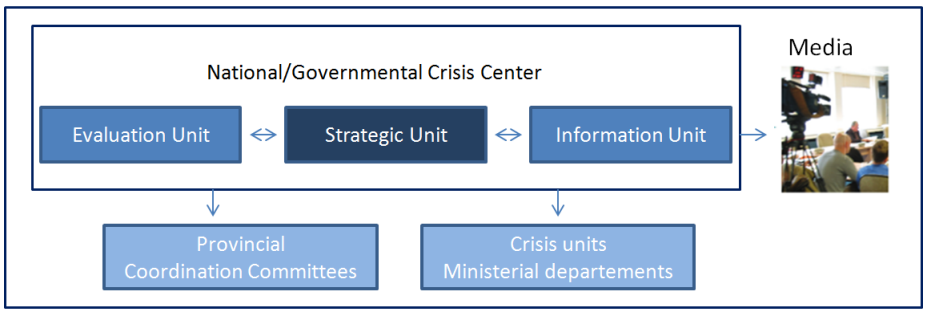

Figure 4.4 The federal coordination structure as described in the national emergency plan (FPS, 2003).

4.4.3.2 Operational coordination

The Director Operations, Dir-CP-Ops is responsible for the (multidisciplinary) operational coordination (RD 2006 Emergency Planning; FPS Interior, 2013). Dir-CP-Ops is the highest ranked officer on the scene (or the person appointed in the monodisciplinary plan) of the discipline most concerned. It is his responsibility to establish a Command Post Operation, the CP-Ops, and to coordinate the multidisciplinary operations.

The CP-Ops is composed of the Directors of the 5 disciplines (minimal composition). They have operational responsibilities and assist the Dir-CP-Ops in the operational coordination. The responsibility of the CP-Ops consists of:

- The drafting of a first operational report of the situation
- Providing information on the evolution of the event to the competent authority(s) and the uniform dispatch centre
- Advising the competent authority on decisions to take and organizing the implementation of those decisions
- Organizing the intervention zone

A specific advisor is appointed by the Dir-CP-Ops to evaluate the occupational health and safety risks for the intervening staff and to propose appropriate measures.

4.5 Organizational structure of the French system

The author of the text in sub section 4.5 is to a large degree based on text received by email from Clément Judek (2016).

The 2004 French law on the modernization of the civil security (August, 13th 2004) resulted in a revised system for emergency preparedness. The ORSEC system has been designed to mobilize and coordinate the civil security response under a single authority (the county Prefect or the Mayor of the municipality depending on the event). It aims to involve more than the emergency services such as, Fire and Rescue services, ambulances and security forces. It prepares everyone who is able, with its own skills, to participate in the protection of the population. Every public or private person identified by ORSEC is able to permanently ensure the missions assigned by the Prefect and prepares his organization's own emergency management (Article 1 of the law). Within the ORSEC system, not only professionals are actors but also each citizen because everyone contributes to the civil security by its own behaviour (Article 4 of the law).

ORSEC allows achieving a proper plan for each organization (infrastructure). However, the main purpose is to set a permanent operational organization that manages important events. It is a common response tool for different types of events affecting different types of organizations.

The acronym "ORSEC" goes with functionality (evacuation, supplying etc.) and the type of the incident (flood, blast etc.) encountered. These specifications go with provisions that are general and specific.

The emergency response is gradual, from a permanent standby state to the general mobilization. ORSEC cannot be triggered, but the director takes the lead and initiates the suitable applications. The ORSEC system is always running. It is supposed to fit the « daily » response and to surge capacity when it is needed by providing adequate resources.

ORSEC is based on:

- A **director** who is able to mobilize all the resources, public or private, that are necessary;
- A **network**: Emergency Medical Assistance Service (*SAMU*); security forces (*police, gendarmerie*); Fire and Rescue Services (*SDIS*); Municipality; County Council; Network Managers (road, electricity, gas…); Companies etc. The common preparedness allows developing a shared operational culture;
- **Risk identification** in order to have a unique directory of foreseeable risks. This directory enables to share a common risk culture and helps the cohesion with the risk prevention policy;
- **Exercises conduction** to implement the ORSEC system;
- Real event management;
- **Feedbacks** for training as well as for real events to assess and improve the ORSEC organisation.

The ORSEC operation system is:

- **Modular**: it is a set of procedures and operational tools that can be used according to the type of incident;
- **Progressive**: the response is gradual regarding the magnitude of the event. The actors will be more and more involved from the daily usual response to the major event;
- **Suitable** for identified foreseeable risks;
- **Adjustable** to any other situation. Since every hazard cannot be planned, the operational response plan is very flexible.

ORSEC includes general provisions regarding the global organization, which is able to fit each situation. It also includes specific provisions related to special risks already identified. These provisions provide the basis of the response encouraging reflex actions.

4.5.1 The general provisions

The general provisions shape the structure which the management of the crisis must rely on.

Missions that shape the basis of the general provisions are:

- Identify all, public or private, actors somehow involved in the protection of the population, in order to make a database that remains updated;
- Leading of the operations: set up of the county operational centre, where the crisis unit manages the event;
- Monitor and observe the state of the situation during the standby period;
- Raise the warning alert.

Then, there are different modes of action for managing the situation encountered:

- Provide assistance to the victims;
- Arrange the evacuation of the population;
- Provide shelters for the victims, supplying food;
- Protect goods, environment and cultural heritage;
- Cope networks problems (electricity, gas, water…).

4.5.2 The specific provisions

The main features of the identified risks are given by the specific provisions in each county (*département*). The specific provisions provide an added value to the general provisions. They include:

- A risk analysis
  - Study of the hazard (potential scenarios; impacted areas, effects, etc.)
  - Study of the assets (concerned municipality; population identification; assets identification; vulnerability assessment)
- Population protection and intervention strategies
- Measures to alert the population
- Specific assignments of the actors (including conventions with associations)
- An updated contact directory of actors likely to be involved

These provisions especially cover natural hazards (flooding, earth quack…), local technological hazards (SEVESO plant, nuclear plant, hydraulic dam…) and the other technological hazards (transport of dangerous goods, airplane crash…).

ORSEC aims to anticipate events based on observation monitoring. The prefecture of the *département* is constantly linked with national organizations such as *Météo-France* (French weather centre) and *Voies Navigables de France* (national expert on inland waterways and river transport). For instance two national reports about the weather situation are sent every day by *Météo-France* to the prefecture of each *département*. From this information, ORSEC enables the preventive deployment of resources regarding the specific provisions of the identified risk.

The elaboration of specific provisions aims to train actors making strategic decisions regarding the event. Thus, even if an identified risk does not occur according to the considered scenarios, actors may have gained experience and technical skills to adapt themselves to the unique situation.

The specific provision design approach can be considered as a real-life emergency situation with the following questions to answer:

- Development of the scenario
  - What type of events can we be facing?
  - What are the involved assets?
- Development of the strategy
  - Based on the scenario, what is the most appropriate strategy to implement?
- Objectives
  - What are the objectives regarding the event and the strategy to implement?
- Action plan
  - What are the actions to be carried out in order to achieve the objectives?
  - Who is in charge of the actions?

This approach allows to:

- Overcome the time constraint induced by the urgency and the need for immediate decision-making
- Engage and involve most of actors and experts on reflexion, who are not easily available during an event

- Consider every possible solution, even inappropriate or unrealistic ones. In the development phase, the error is possible and of no consequence.

4.5.3 Emergency plans

Emergency plans are considered as making part of specific provisions. There are developed regarding identified risks by the relevant actors who are the most adequate to cope with it. These documents are shared with the county prefecture (*Préfecture de département*) and the Fire and Rescue Services (SDIS).

4.5.4 The basic principle of the fire and rescue services (SDIS)

Although the Fire and Rescue Services are ruled by the Ministry of the Interior, they are decentralized in each county (*département*). They depend on the county prefect (*préfet de département*) for the operational implementation.

4.5.4.1 The fire and rescue services global missions

The SDIS is responsible for the prevention, protection and fight against fires. Furthermore, the SDIS, in collaboration with other services and professionals, is in charge of the assessment and prevention of technological and natural risks as well as emergency rescue.

The SDIS has the following responsibilities:

- Prevention and assessment of civil security risks
- Preparation of preventive measures and response means
- Protection of property and the environment
- Emergency rescue to victims of accidents, disasters or catastrophes and their evacuation

4.5.4.2 The fire and rescue services missions in large scale events

The SDIS receives and processes emergency calls and commits the required emergency resources. It reports to the Prefecture of any event likely to have consequences for civil security and shares information with relevant services such as ambulances called SAMU (*Service d'aide médicale urgente*).

Under the direction of the Prefect who is the director of the operations (*Directeur des Opérations de Secours*), the director of the SDIS, or a representative, takes the command of operations (*Commandant des Opérations de Secours*). The operation commander is responsible to implement on the field the strategy elaborated by the director of operations within the county crisis centre. The operation commander is in charge of the involvement of adequate means and, if needed, can ask the director of operations for additional means in support. Whether the needed means are not available in the county (*département*), the director of operations refers to the Defence area level to get external means (fig.1).

4.5.5 Large scale event management

According to the severity of the incident, the emergency response is ruled in a different way. Figure 4.5 highlights the links between all the administration levels. First of all, for a limited incident occurring inside the municipal boundaries, the security services of the town manage the crisis. Otherwise, when the effects of an incident are major, the Prefect of the county leads the operations in order to provide more human and technical resources and to coordinate the

actions. The Mayor always keeps the mission of protecting the population of the town even if the Prefect takes the leadership. The other levels, such as, Defence area level, Nation level and European Union level, support the local response by coordinating and providing specific and numerous resources.

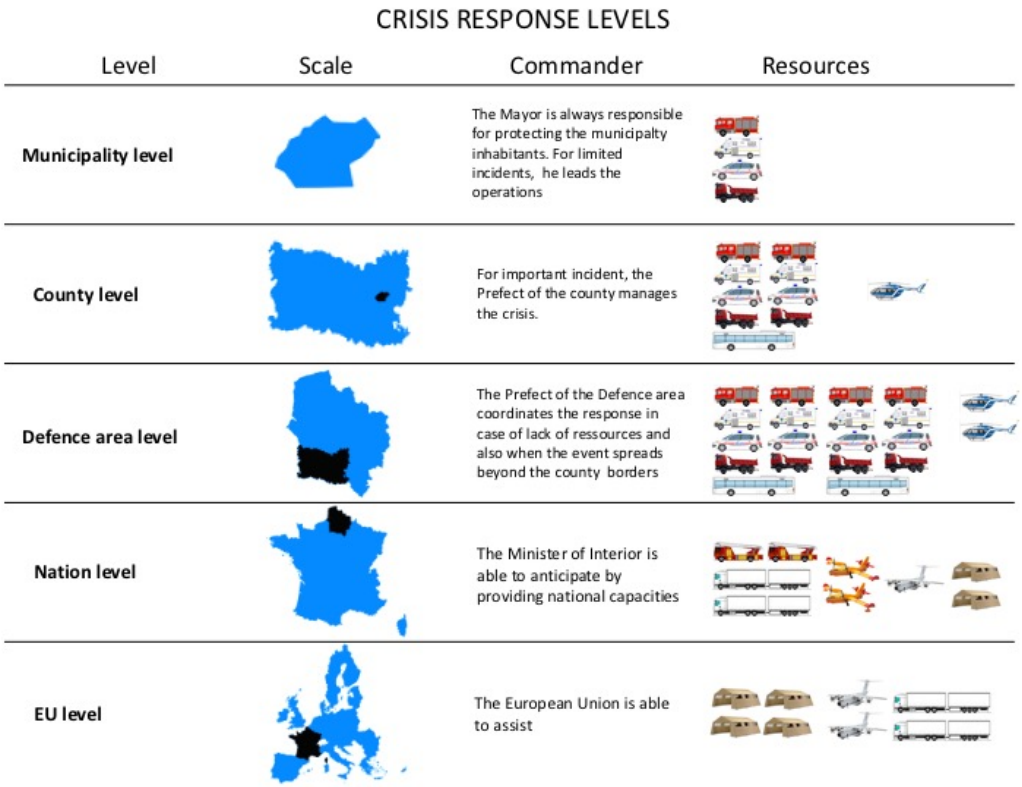

Figure 4.5 Organization of the emergency response levels in France

4.5.5.1 Leading organization

Table 4.4 shows that there are two potential leaders. For a local response, the leader of the operations must be local. This is the reason why the Mayor manages the response for ordinary incidents. When the event exceeds the response capacity (human, technical and spatial) of the municipality, the Prefect becomes the leader.

Table 4.4 Examples of the organisation of the operations leading

CASE	CARACTERISTICS	ACTORS	LEADER OF THE OPERATIONS
Car crash Limited incident	Localised Short duration Immediate consequences	Emergency services (usual response)	Head of the service involved
Car crash Important incident	Localised Few hours Immediate consequences	Emergency services (with resources reinforcement)	Mayor
Car crash with many victims Transport of dangerous goods accident Fire with particular effects (industrial, tunnel...)	Localised Few hours Immediate consequences	Emergency services (specific reinforcement)	Prefect
Industrial incident Pollution (oil spill) Flood	Part of the county affected Few days Progressive consequences	Emergency services (specific reinforcement)	Prefect
Storm Pandemic Major flood Nuclear incident	Part or entire county affected Few days or weeks Progressive consequences	General mobilization of services and resources	Prefect

4.5.6 Emergency management process

There is no decision-making model imposed by regulations in France. Each service works with its own practices. Nevertheless, the ORSEC system which centralizes all the information at the county prefecture, provides a global approach of the information treatment (Figure 6). The operational services inform the prefecture which decides the strategy of response by triggering or not a specific plan and the crisis centre. This decision is made in consultation between the Prefect and the first responders.

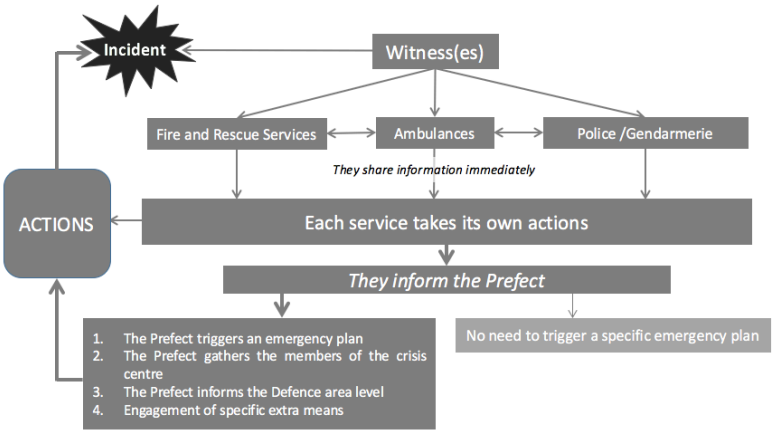

Figure 4.6 Event occurrence management process

When the Prefect decides to trigger an emergency plan, general as well as specific provisions are made. Based on these provisions, the Prefect gathers the adequate members that will constitute the crisis unit. The permanent members are:

- A representative of the *Préfecture* authority (the Prefect or the Cabinet Director)
- A representative of the Defence and civil protection joint ministerial service
- A representative of the Police
- A representative of the Fire and Rescue Services
- A representative of the *Gendarmerie* (army police forces)

- A representative of the *Direction Départementale des Territoires* (State service in the county for land use planning and sustainable development)
- A representative of the *Conseil départemental* (Council that administer the county)

These permanent members are joined by experts regarding the type of incident to cope with. For identified risks, this list of additional members is already prepared and is included in the associated emergency plans, but the list remains adjustable. Example of additional members are:

- A representative of the power supply service (electricity or gas)
- A representative of the highways company
- A representative of the national rail company
- An expert in chemistry
- An expert in environment
- Etc.

4.5.6.1 Reflexion methodology for making strategic decision

While coping an important event, the crisis unit lead by the Prefect must elaborate a strategy that will draft the decisions to be made (Figure 4.7). The first ideas given by the crisis unit to draw an action plan rely on three elements: a clear view of the event global context; the set of objectives and the needed means to achieve the determined objectives. As soon as these elements are studied, then the action plan will be discussed and adapted based on the advantages and disadvantages that have been highlighted. This primary work done in collaboration with first responders and experts supports the decision-making process.

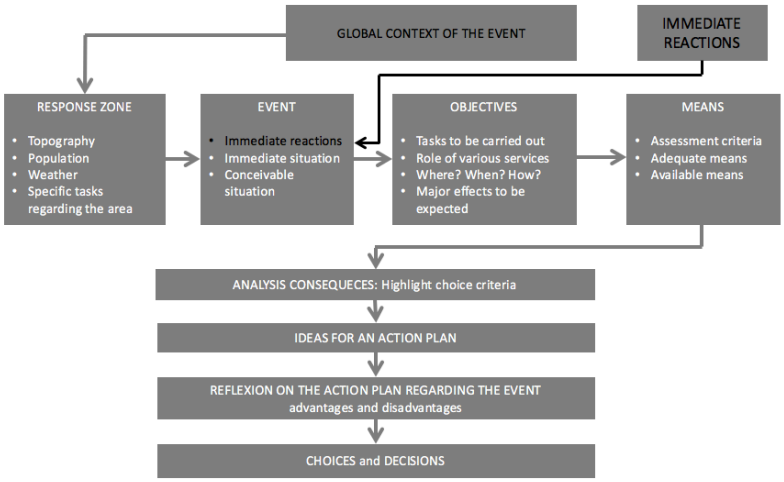

Figure 4.7 Strategic reflexion methodology

There is no model to elaborate a global coping strategy in France. However, the ORSEC system involving any actors susceptible to mitigate the situation, enables reflex actions from each service. This reflexion can be made thanks to the coordination between the actions of individuals on the field collecting scattered information as well as implementing different commands and the consultation between the members of the crisis unit making a global representation, judgements and decisions.

4.6 Organizational structure of the Dutch system

The main goal of emergency management is to 'Do the Most for Most', meaning treating as many victims in the best way possible, and returning to "normal operating procedures" as quickly as possible. (Hustinx et. al., 2004) Second objective is to minimize damage, since indirect damage can easily be (much) larger than the direct damage. In case of a complex incident and possibly an insufficiency of resources, which often occurs at (the start of) major incidents, calculated decisions must be made about how to manage the incident. As making these decisions is very complex, emergency management is the work of educated professionals and, like in all other developed countries, the Netherlands has an elaborate structure of emergency management defined in legislation. (EMDM, 2007; GRIP Wikipedia, 2014)

Like most countries, the Netherlands is divided in 10 Police regions and 25 Safety Regions for effective emergency response. Each Police region contains one or more Safety Regions and each Safety Region consists of multiple municipalities. Emergency services are organized according to these regions. The 10 Police regions are governed by the Netherlands National Police and the Safety regions by the Ministry of Safety and Justice.

4.6.1 Emergency management process

To effectively deal with incidents of all sizes in a consistent and well-defined manner, over the past few years the Netherlands has adopted the so called GRIP emergency management structure. GRIP stands for Coordinated Regional Emergency management Procedure ("Gecoördineerd Regionale Incidentsbestrijdings Procedure"). GRIP has seven phases, ranging from "GRIP 0" up to "GRIP Rijk". (GRIP Wikipedia, 2014) Figure 8 gives the complete line of command, including the GRIP phases and as reference the internationally often used Bronze, Silver, Gold and Gold+ command levels.

GRIP 0: incidents not requiring centralized incident coordination. As such GRIP 0 is not a real phase, but often called so in daily work requiring a limited amount of joint-agency efforts.

GRIP 1: incidents with effects contained within the incident scene and requiring inter-agency cooperation. A joint-agency incident command team (CoPI) is set-up on scene, chaired by the incident commander (most often the most senior fire officer in rank).

GRIP 2: incidents with effects outside the incident scene. Off scene, an operational team and possibly action centres for each involved agency are activated. The operational team is led by the operational leader; an agency independent officer (i.e. can be a fire, police or medical officer). In case one hospital cannot manage all victims, the medical command structure is widened to distribute victims amongst multiple hospitals and all involved hospitals activate their disaster management procedures.

GRIP 3: incidents with large consequences for the population within one municipality. The mayor of the effected municipality with his/her policy making team and the police commissioner and public prosecutor of the affected (Police) region are included in the emergency management structure.

GRIP 4: incidents with large consequences for the population within multiple municipalities. The chair of the effected Safety Region (in most cases the mayor of the largest municipality in the Safety Region) and a regional policy making team are included in the emergency management structure.

GRIP 5: incidents originating in one Safety Region but affecting multiple Safety Regions. The chair of the Safety Region in which the incident originated is in command. He or she is supported by the chairs of the other affected Safety Regions. Each region has its own operational and policy making teams. GRIP 5 is therefore a combination of GRIP 4 in multiple regions.

GRIP Rijk (National GRIP): Incidents in which the national security is threatened. The Ministerial Commission on Crisis Management (MCCB), in which several applicable ministers take seat, takes over overall command. The National Crisis Centre and the National Operational Coordination Centre are activated (if not yet done so in a supporting role in lower GRIP phases).

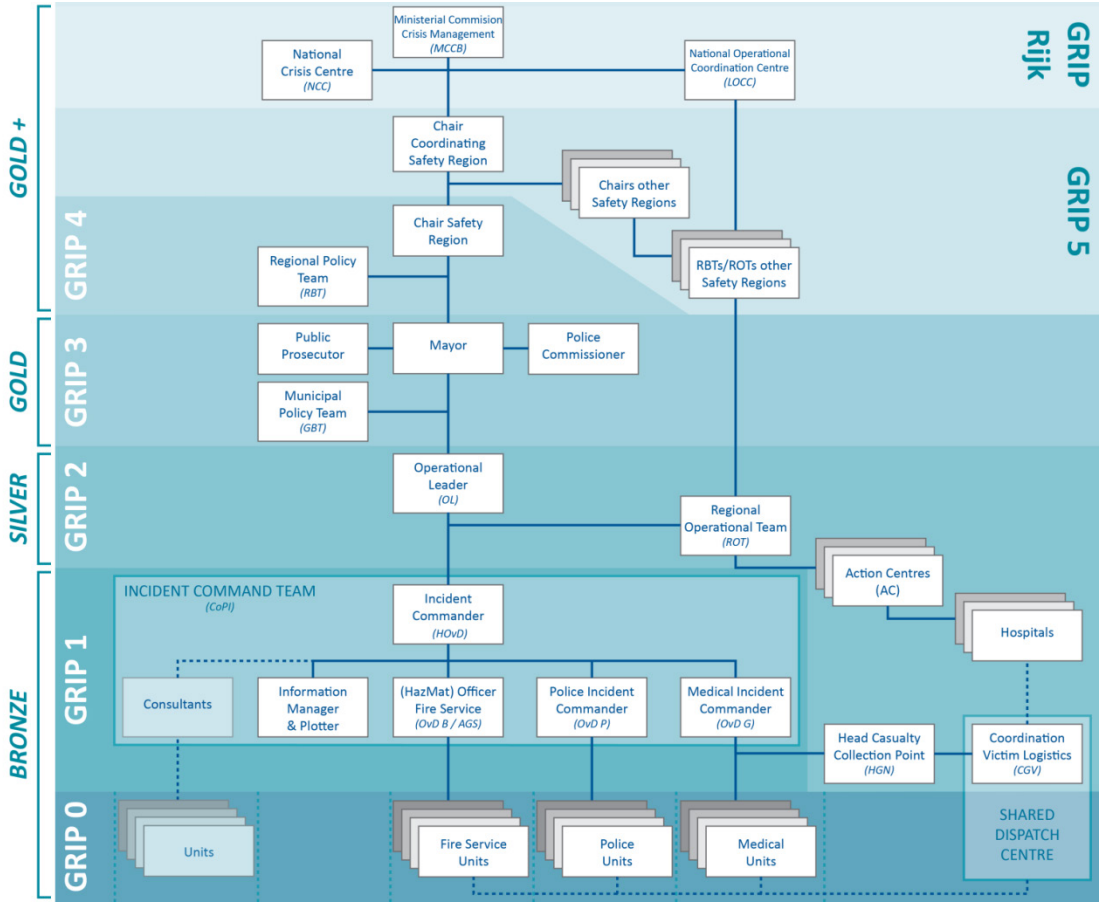

Figure 4.8: GRIP emergency management structure as used in the Netherlands (based on Van Campen, 2010)

The GRIP structure is a flexible emergency management methodology in which the highest in command can at any time scale up or scale down with one or more phases, according to the current state of the incident. GRIP is incident dependent, not regional dependent, meaning that within one municipality or Safety Region multiple incidents each with their own GRIP phase can be managed in a single moment in time (e.g. a large GRIP 2 fire and a major medical incident requiring GRIP 3 within the same city).

Apart from governmental agencies, the GRIP structure allows other professionals (e.g. NGO's, power suppliers or industrial firefighting brigade) to be included in the line of command and as such in the emergency management structure. The Incident Command Team and Regional Operational Team are often assisted by consultants and incident managers from commercial companies or other institutes if the incident originates from or severely affects these institutes.

4.7 Relevance for the tasks

4.7.1 Who is responsible?

In an emergency event where there are multiple response agencies, all countries describe that no single agency can command and control personnel in other agencies, however all agencies are responsible for cooperating with each other in a direct and efficient way. Therefore there is always one agency that is responsible for having the broad view over the emergency event and setting up the overall strategy and goals of the operation. For rescue operations in the Netherlands, Sweden and Belgium it is the fire service who often leads the operation while in the UK and Norway it is the police.

Incidents with possible cascading effects put strains on society and affect a lot of different important functions. All countries have management systems that allow for scaling up when needed and the local government often gets involved in large scale events. The local government or people with important roles in society can then form a crisis management committee or similar. Their duties are to have the overall picture and make strategic decisions and set overall goals. When a broader geographic area is affected and multiple municipalities are involved a province/county/region (or similar) can take over the leadership and have responsibility to have the overall picture and to coordinate all activities during the event. As a final step the state have emergency plans on how to coordinate if the event scales up to affect more than one province.

4.7.2 How are reporting structures set up?

All countries describe that they use three different command levels (in the Netherlands there are seven). Even if the names of the three levels are slightly different, the context is the same. The main first responders are fire service, police and ambulance service. In France, the mayor or the prefect are more involved in emergency management and the first responder always inform them about the situation in order to be ready to intervene. Belgium makes a clear distinction between daily rescue operation and emergency management of large scale events. Whenever the incident reach the criteria of being a large scale event they have an organization for scaling up with a coordination committee including the mayor or governor (depending on the size of the incident) and representatives from the five disciplines involved (see table 4.1).

The communication between different levels within an organization is often vertical within the hierarchy. Between different organizations it is often the highest levels that communicate and share information. In France for example they have the ORSEC system which centralizes all the information to one authority. Meaningful and effective communication is supported by joint working and understanding of each organization's responsibilities and capabilities. The used of a common language is important for understanding. In all countries, except Sweden, there is an attempt to implement a national ICS to ease the understanding of roles and responsibility, especially in large scale events when there are multiple agencies involved. For Sweden it is especially in the fire service there can be a problem with different nomenclature for different roles. This is due to the strong local self-government.

4.7.3 Decision-making

In an emergency management process there are specific key-points for when and how to scale up or down the management of the incident. Mostly the emergency management process starts with someone calling 112 to a dispatch center. The operator who answers is the first person who prioritizes the call and decides what kinds of resources to dispatch. The operator often has a checklist and depending on the information he/she gets from the caller a triage is made of what kind of resources that will be dispatched. The checklist is a good tool for daily relief rescue operations, but is limited when it comes to large scale events (with possible cascading effects). The emergency call operator is the first person to decide what kind of resources to dispatch. But after that it is the incident commander. In a small accident, the incident commander is on the scene of the accident but sometimes the incident commander can be in a command center instead and therefore the person is making decisions based on communications with the officer on scene.

An incident with cascading effects often put strains on the authorities involved in the rescue operation and often many actors are involved. It is important to cooperate and coordinate all actors involved. The need of scaling up and involve more actors in the emergency management process are important. For example in France where the ORSEC system is used first responders (police, fire and rescue services and ambulance) always inform the mayor or the prefect, who then makes a decision on the need to trigger a specific emergency plan or not. The decision is made in consultation between the prefect and first responders. The system aims to involve more than the emergency service and are designed to mobilize and coordinate the whole spectrum of people/organizations that might be involved during an incident under one authority.

In Belgium the definition of when to trigger a specific emergency plan and set up an emergency committee is “every event that causes or could cause a damaging impact on society (such as a serious disturbance of public safety/security, a serious threat to live or the human health or to important material assets) requiring the coordination of disciplines to eliminate the threat or to limit the damaging consequences”. In Sweden the definition is “an event that deviates from the norm, implies a serious disturbance or imminent risk of a serious disturbance in important societal functions and requires urgent action by a municipality or a county council”.

Incidents with cascading effects live up to both definitions but then it must be known that the incident may have cascading effects. To be able to stop cascading effects it is also important to know what kind of cascading effects that can occur, because then it is possible to get the right kinds of resources (material, personnel etc.). During an incident an IET can help decision-makers on the strategic level to decide on when to scale up management and what kind of resources are needed.

5 Decision-making in the lab and in the wild

This chapter gives an introduction to the field of decision science, starting off from early developments around individual cognition and arriving in ecological models based on studies of real-world operations, with a description of the underpinnings of situated decision-making and a more elaborated account of Recognition-Primed Decision-making (RPD), with the mention of some organizational factors that can impact decision-making. The aim of the chapter is to examine the validity of this research for the tasks included in the DoW such as

decision typologies, key points, rationales, locality, distribution and information sharing with particular respect to cascading effects, and also for the development of the IET.

5.1 Heuristics and Biases

Early theories on decision-making were largely based on very limited decision-spaces such as gambling situations. It was theorized that humans make decisions based on a rational process, pursuing the decision path with the maximum expected utility. Humans were envisioned to function as rational agents or "Homo Economicus" that solve problems by iterating over all decision alternatives, making decisions based on probabilities (Simon, 1955). During this period research was focused on fitting human behavior to "optimal" decision strategies built on standard logic (Sahlin et al., 2009).

In the 1970's this paradigm was questioned on the basis of experimental research. These experiments showed that people routinely deviate from normative logical decision-making. Daniel Kahneman and Amos Tversky performed studies where participants were demonstrated to apply mental "rules-of-thumb" or heuristics when solving problems involving probabilities (Tversky & Kahneman, 1974). Kahneman and Tversky observed a number of cases where these heuristics led to errors in reasoning. Their participants tended to ignore base-rates about populations when making judgments, they did not consider sample size when judging probabilities, they ignored regression toward the mean, they had misconceptions around chance and they tended to anchor numerical judgments to other numbers arbitrarily present in the test environment. Moreover, even though participants were made aware about uncertainties in the information that they based their judgments on, they typically displayed a strong confidence in their own judgments. It was concluded that heuristics would often lead to "severe and systematic errors" in decision-making. Although many of the early experiments mostly involved student participants, studies were also made on professionals (e.g. stock-brokers) displaying the same behaviors. A decision bias, it was concluded, is not caused by a lack of knowledge, false beliefs, inappropriate goals or lapses of memory, attention or motivation. Instead it is a systematic flaw in the relationships between a person's judgments, desires and choices. (Cohen et al., 1993).

Wilke and Mata (2012) present a summary of a number of biases in human reasoning that were found to deviate from classical, logical models of decision-making. These are presented in Table 5.1. The table also includes some bias identified by other researchers that are not necessarily connected to probabilistic judgments but where cognitive heuristics still can lead to faulty conclusions.

Table 5.1 A selection of heuristics and biases relevant for the current task

Representativeness heuristic	Assessing similarity of objects and organizing them based around the category prototype (e.g., like goes with like, and causes and effects should resemble each other) – Perhaps only a problem when experience is lacking so that representativeness is based on "folk" models?
Availability heuristic	The first thing that pops into a person's mind when making a judgment is given the most importance (e.g. the latest piece if information acquired)
Imaginability heuristic	Similar to availability, when a decision demands that alternatives are imagined the one easiest to imagine is

	preferred
Confirmation bias	The selective search for information that confirms a person's preconceptions
Illusory correlation	The tendency to perceive correlations between actions and effects even when there is little evidence for it
Fundamental attribution error	Personal factors are over-estimated and situational factors are under-estimated when explaining other people's behavior
Gambler's fallacy	A tendency to think that the probabilities of future outcomes are affected by earlier outcomes
Hindsight bias	The tendency to view an event as foreseeable after it has occurred, even if there was little ground for such a conclusion beforehand.
In-group bias	Favoring members of one's own group over people from other groups, e.g. with regard to their judgments and actions

5.2 The rise of ecological models

In 1989 a group of researchers came together for a conference in Dayton, Ohio on the subject of decision-making in natural environments (Endsley et al., 2007). These researchers were brought together by the fact that studies of a large variety of professionals such as firefighters, nuclear power plant controllers, Navy officers, Army officers and highway engineers had seemed to uncover common traits in decision-making. These were environments where the effects of incidents could easily spread to neighboring systems, involving other professional groups. When expert practitioners made decisions in real-world situations, their decision-making processes showed features that were not concurrent with formal models. Moreover, these experts did not seem particularly prone to the plethora of cognitive bias identified by experimental psychologists. The conference in Dayton was sponsored by the US army that had become interested in the decision sciences after the incident where an Iranian commercial airliner was mistakenly shot down by the United States Navy guided missile cruiser USS Vincennes (Klein, 2008). Although this incident had disastrous outcomes, it gave rise to many questions around the basis for decision-making in professional contexts. Some of the first observations on expert decision-making had been made in the study of professional chess players. In a game of chess the number of possible positions quickly reaches the billions. When the observed chess masters played however, they naturally could not iterate over the whole set of possible plays for every move. Instead they were typically able to find the most promising moves very quickly, while mediocre players often did not consider the best moves (Kahneman & Klein, 2009).

Based on this kind of studies of expert decision makers, a critique had been evolving toward the experimental characteristics of the heuristics and bias research. This research seemed to have exposed human decision-making as a fragile and flawed process compared to normative logical alternatives. On the other hand, it was noted, the sole purpose of experiments such as the ones carried out by Kahneman and Tversky was in fact to expose cognitive weaknesses and subjects were not selected randomly (they were typically students). When "rationalist" psychologists found differences between formal decision models and the behavior of humans,

this was attributed to the irrationality of decision makers rather than to flaws in the model (Cohen et al., 1993).

Soon the ideas that challenged prior findings around decision-making would come together under the description “Naturalistic Decision-making” (NDM) with the aim of describing how people make decisions in real-world settings (Klein, 2008). These researchers were unified by the notions that contrary to experimental conditions in lab sessions, professional decision-making is carried out in information-rich environments, stretched out in time, with redundant cues, feedback from earlier actions and often with shared responsibility. Despite this however, experts often have great success navigating these deep waters. Even if single decisions are biased, environmental factors may serve to prevent bad outcomes. Even if a person’s decision-making process is imperfect, that person’s real-world knowledge can enable very swift and effective actions. While cognitive heuristics undoubtedly lead to simplifications that sometimes go too far, the benefits of reduced cognitive effort and speed can often make it superior to formal procedures (Cohen et al., 1993).

Results from the first years of NDM research were collected in the 1993 book Decision-making in Action: Models and Methods (Klein et al., 1993) where Raanan Lipshitz makes a summary of a number of complementary models. These models have several common features in that they all describe dynamic processes of decision-making that are context dependent where the decision maker makes some sort of situation assessment and uses mental imagery.

Jens Rasmussen makes a classification of three different types of information processing involved in decision-making: skill-based, rule-based and knowledge based behavior. These types refer to different levels of conscious control over a person’s activities. Skill-based behavior is smooth, carried out directly without explicit reasoning. Decisions are based on a dynamic mental model of the decision maker’s environment, enabling adjustments based on feedback from previous actions. Rule-based behavior is guided by rules and know-how that the decision-maker can state explicitly. Both skill-based and rule-based behaviors are typical for expert performance and are appropriate for familiar situations. Knowledge-based processing on the other hand is demanded for novel situations where no routines or rules exist. More information is needed on specific conditions and where objectives and options have to be explicitly considered. Here the decision-maker is involved in a very conscious process of formulating goals, making plans and trial-and-error.

Another theory is presented by Hammond who views all cognitive work on a continuum ranging from intuitive to analytical thinking (Klein, 2008). According to Hammond, intuitive thinking is used for ill-structured tasks while deliberate, analytical thinking is used for well-structured tasks. His studies showed that decision makers tend to become more analytical when snap judgments fail and more intuitive when careful analysis fails. Hammond’s inducement principle states that the task situation induces a certain type of process. When large amounts of information have to be processed in a short time intuition is induced, while a task where quantitative information is presented sequentially induces analysis (Klein et al., 1993). These points toward the conclusion that the underlying nature of a decision task has to be understood in order to understand how it can be tackled and how decision-making can be supported.

5.3 Making sense of the situation

In a 2015 article that presents an overview of the development of NDM, Klein notes that the greatest challenge for decision makers in professional settings is not choosing between alternatives but making sense of events and conditions (Klein, 1998). Mobilizing emergency

response requires a continuous process of monitoring, updating, integrating and communication vital information to multiple operational components (Hardy & Comfort, 2015). This issue of how professionals work up to a decision by examining states and events in their environment has developed into a research field of its own. Several partly overlapping concepts have been suggested such as Situation Awareness (Endsley, 1995), Sensemaking (Weick, 1995), Shared Mental Models (Van Santen et al., 2009), Common Ground (Lundberg et al., 2011) and Common Operational Picture (COP) (Lass et al., 2008).

5.3.1 Situation awareness

The concept of Situation Awareness (SA) has its roots in aviation and started appearing in the decision science discourse in the late 1980s. In essence, SA is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future (Endsley, 1995). The ability of an operator to develop situation awareness depends both on innate cognitive abilities, experience, training, preconceptions and goals. Endsley describes SA in terms of three phases. In the first phase elements in the environment are perceived. After this the operator makes an interpretation of his or her perceptions and creates meaning that is relevant to the task. Finally the operator's construct of the situation is used to make predictions about future events in the work environment. Figure 5.1 shows how these phases are integrated with other resources or functions such as the decision-makers preconceptions, experience, abilities and training, goals and objectives, how this process is affected by environmental factors and how the outcomes of decision and action turn into feedback to situation awareness. Other divisions of the concept have also been proposed. For example, Jungert, Hallberg and Hunstad (2006) describe situation awareness in terms of operational features. *Organizational Awareness* is the understanding of available resources and their possible use, *System Awareness* concerns knowledge about supportive technology and *Environmental Awareness* refers to knowledge about contextual factors and risks. To these descriptions, *Activity Awareness* has been added to cover the actions and intents of people working around the operator. This concept has been expanded under the heading of *Shared Situation Awareness* (SSA). This shared awareness concerns whether the members of a team make similar interpretations of events and whether they understand the needs of other people (Comfort, 2007).

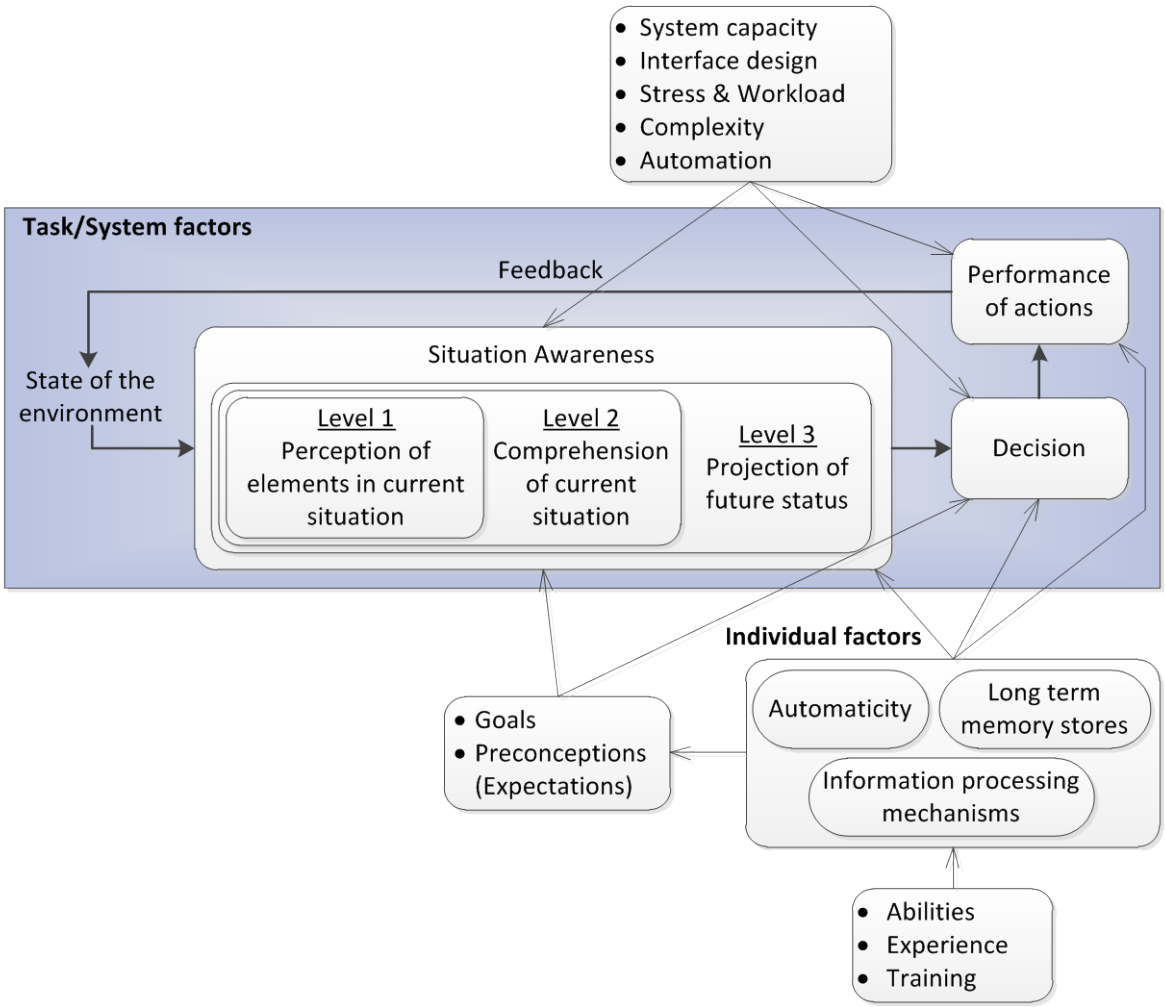

Figure 5.1 Creation of situation awareness (Endsley, 1995)

5.3.2 Sensemaking

The concept of Sensemaking bears many resemblances with SA and is described as a continuous, adaptive process that people employ to guide decision-making (Jensen, 2009). Weick, one of the foreground figures behind this concept, separates sensemaking from other macrocognitive processes such as problem detection, problem identification, adaptive planning and decision-making. Through this process people identify problems, construct meaning, frame new information and create causal explanations (Weick, 1995). Sensemaking begins when a person becomes aware of a problem: a change, anomaly or surprise in the situation that initiates the gathering of additional information (Militello et al., 2008). When a person acts on his or her understanding, this produces feedback that reflects information about the validity of one's sensemaking. Sensemaking depends on past experiences, current goals and also individual differences in how people attend to, select, categorize and integrate information. This concept has also been connected to the theory of RPD in the sense that incoming information may suggest frames or mental models for organizing and understanding (Klein et al., 2007). The so called data-frame model reproduced in figure 5.2 attempts to describe how such a process might function (Moore & Hoffman, 2011).

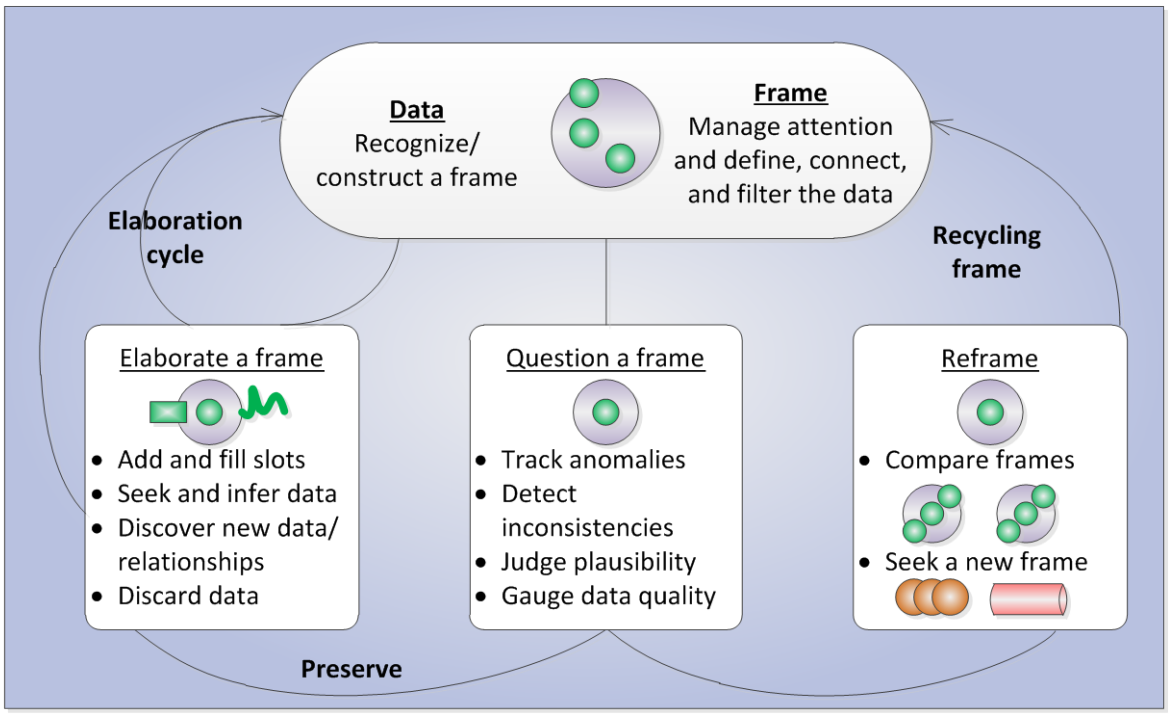

Figure 5.2 A model of sensemaking (Moore & Hoffman, 2011)

5.3.3 Mental models

According to Endsley et al (2007), the concept of Mental Models differs from SA in that the former evolve more slowly while SA can change from moment to moment. By some authors this has been described as the product of sensemaking (Klein et al., 2006). According to the definition by other authors such as Van Santen, Jonker and Wijngaards (2009), the creation of mental models approaches descriptions of how situation awareness is acquired, and they also stress how the collaborative nature of emergency response demands that people work to create shared mental models. These authors list four domains of mental models in working teams:

1. Knowledge of equipment and tools used by the team
2. Understanding of the work that the team is to accomplish, including its goals or performance requirements and the problems facing the team (task mental model)
3. Awareness of team member characteristics, including representations of what individual members know and believe, their skills, preferences and habits (team member mental model)
4. Knowledge or beliefs of team members with regard to what are appropriate or effective processes (team interaction model).

Based on observations in the field, Van Santen et al also list a number of circumstances that typically improve the creation of shared mental models. This is facilitated if there is a belief of shared ownership within the group, when self-evaluation and self-correction takes place, when there is an active sharing of information based on mutual respect, when team members are experienced in crisis management decision-making and when there is an everyday organizational context that supports working in self-managing teams.

5.3.4 Common operational picture

Effective decision-making is possible when relevant participants receive timely and accurate information thoroughly analyzed and filtered for ultimate decision-makers' convenience. (Kapucu & Garayev, 2011). While the concepts of situation awareness, sensemaking and mental models primarily allude to mental or social processes, Common Operational Picture (COP) refers to manifestations of these mental functions, often in the shape of a system for information and communication (Norros et al., 2009). Comfort (2007) discusses the response to Hurricane Katrina in terms of COP. Here she stresses that a COP is supposed to facilitate sharing of information. According to Comfort's observations, human capacity to recognize risk depends on the timeliness, accuracy and validity of information and the establishment of a COP can replace strict hierarchies that otherwise may restrict the flow of information and undermine a shared perspective. The capacity for coordinated action in multi-organizational settings will likely increase when information can be transmitted simultaneously to different stake-holders. This may create a common ground between responders which enables predictability among them (Bergström et al., 2010). When information is shared, however, it is important to focus risk data in formats that are relevant to the responsibilities of each major decision maker. Supplying information is also a matter of balance, both with regard to information quality and information load (Kapucu & Garayev, 2011). Comfort (2007) also notes that the formation of a COP will typically start well before an actual event, during years of common training, shared experience and professional interaction among emergency response personnel.

5.4 Recognition-Primed Decision-making

The main driving force behind the early work of Klein was to find out how people are able to make hard decisions under circumstances of limited time, high stakes, vague goals and unstable and uncertain conditions (Klein, 2008). These are traits that are typical for emergency response situations and where uncertainty may be particularly associated with cascading effects. Indeed, Klein based much of his research on studies of firemen working in real incident scenarios. His main observation was that these decision makers rarely listed and compared alternatives the way formal models would prescribe. Instead they assessed the situation and selected an action based on this assessment (Klein et al., 1993). This kind of process is mainly based on understanding and recognition. When a person has made sense of the relationships between individuals, events and actions, they usually know how they want to act based on previous experiences (Masakowski, 2008). Cognitive patterns can hold information about cues, expectancies, plausible goals and typical reactions, enabling the very rapid responses that for example can be observed during emergency response (Klein, 2008).

Klein refers to this process as Recognition Primed Decision-making (RPDM) and describes three main phases observed in fireground commanders, summarized below by Lipshitz (Klein et al., 1993) and seen in figure 5.2.

1. **Situation recognition**. The decision maker recognizes/classifies the situation as typical or novel through pattern matching. Typical situations lead to typical or well-rehearsed actions, and novel situations demand other ways of constructing a response.
2. **Serial option evaluation**. In the next step action alternatives are evaluated until a satisfactory one is found. According to Klein's theory, actions are selected from a cognitive action que where the first element is the most typical response in the particular situation. This means that the first action evaluated will be the most typical

response for the situation. These ideas are to some extent parallel to theories on cognitive schemata investigated by researchers such as Jean Piaget.

3. **Mental simulation**. The action that has been selected is then evaluated using mental simulation i.e. the action, its consequences and possible problems are imagined.

Klein describes the RPD model as a combination of intuition and analysis where intuition can be understood more or less as recognition (Kahneman & Klein, 2009). The first step of pattern matching draws on intuition while mental simulation involves analytical reasoning. Both types of processing are necessary, because intuition alone may point to faulty options, and analysis alone is too slow for many real-world situations (Klein, 2008).

In the years following Klein's initial publications similar observations have been made in a wide range of fields such as police work, critical-care nursing and military decision-making (Klein et al., 2003). People in both professional and private settings make most decisions using recognitional strategies. This pattern is more pronounced for experienced persons, while novices tend to be more analytic and deliberative. With increasing experience they spend more time examining the situation and less time comparing options. What separates experts from novices then mostly lies in their ability to assess the situation, not in their general reasoning skills. Working up to a decision is tightly connected to action as the decision maker creates his or her own feedback, updating a mental representation of the situation (Njå & Rake, 2009). This means that experience is an invaluable asset in emergency response, but also that the decision environment for responders should provide good support for the construction of sound, shared mental models (van Santen et al., 2009).

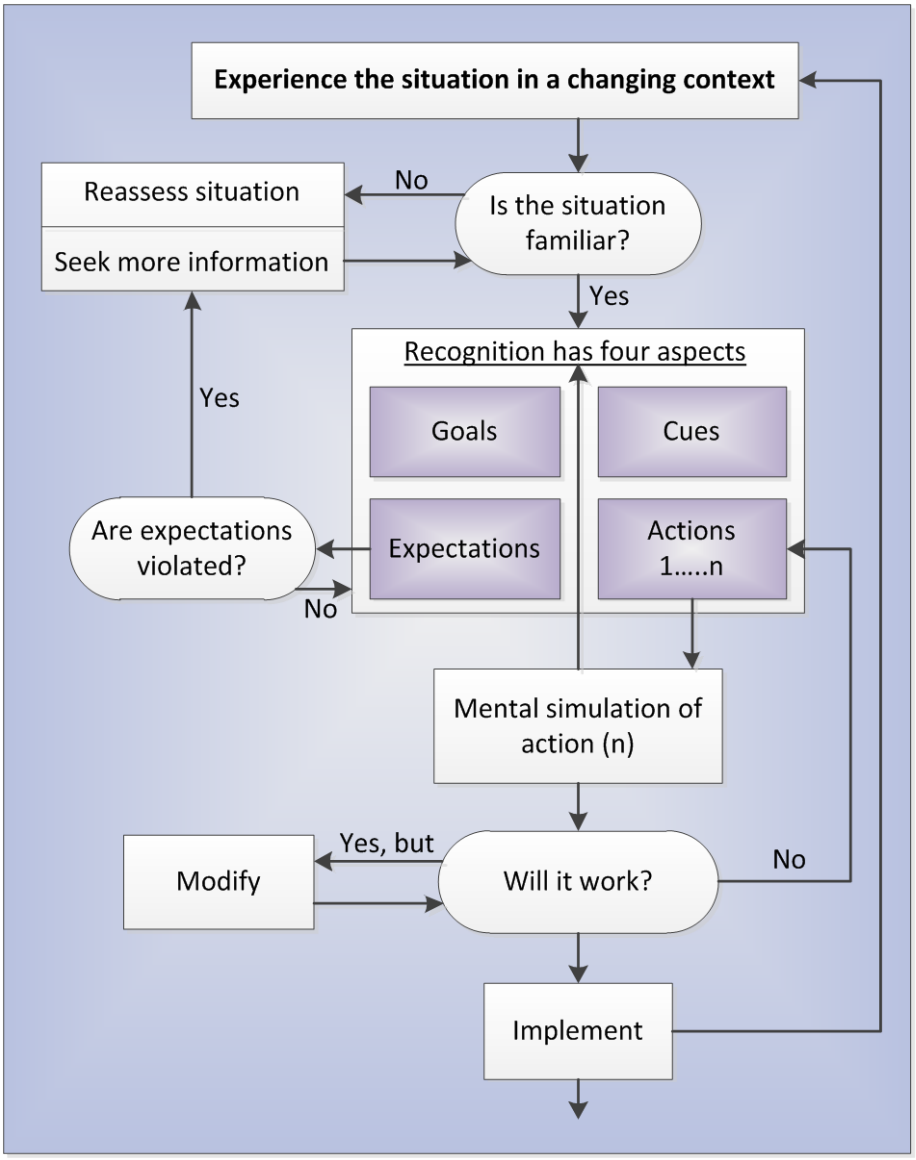

Figure 5.2 A model of RPD (Klein et al., 1993)

5.5 A synthesis of HB and NDM

HB and NDM have long been considered rival paradigms but in 2009 the most prominent figures within the respective fields, Daniel Kahneman and Gary Klein, published a joint article with the intent of reaching a common ground between heuristics and expertise (Kahneman & Klein, 2009).

Klein has earlier emphasized that RPD is not a universal model of decision-making. Rather it is a model that is likely to be encountered under time pressure and with high levels of expertise (Klein et al., 1993). Kahneman and Klein echo this view in their joint article (Kahneman & Klein, 2009). Heuristics are useful but sometimes they lead to errors. The answer to when intuitions can be trusted and when they are susceptible to errors lies in the working context of the decision maker. Skilled intuitions will only develop if that environment is sufficiently regular, so that cues can be used effectively for pattern-matching. Kahneman and Klein use the term validity to describe this. Validity in this sense is the causal and statistical structure of the

environment. In high-validity environments there are stable relationships between cues and subsequent events or outcomes of actions. Two examples given by the authors are medicine and firefighting. For example, there will often be early indications that a building on fire is about to collapse. Low-validity environments on the other hand display weak regularities so that outcomes are very hard to predict, for example predictions on the development of a particular stock on the market. High-validity environments provide the right circumstances for expertise to develop. The opposite is true for environments that undermine human learning. Environments that provide little opportunity to learn from feedback will diminish the role of experience and open up for basic heuristics and errors. In these low-validity environments the use of statistical algorithms may produce better results (or less bad results) than experts.

The overall conclusion of the authors is that HB and NDM basically studies two different phenomena. NDM is occupied with intuitive judgments that are based on experience and that manifest skill, as well as the factors that help in the acquisition of skill. HB on the other hand studies judgments that are based on simplifying heuristics where experience has little impact.

5.6 Organizational factors

When disasters strike today, effects often spread across organizational, regional and even national borders (Van Santen et al., 2009). In the US, failures in the responses to Hurricane Katrina and the 2001 terrorist attack at World Trade Center awoke an interest in collaborations and partnerships within the broad range of actors in emergency management (Kapucu & Garayev, 2011). Real-world operations will often involve many agencies and when that is true, quality of communication may be affected by inter-organizational tensions, to the extent where agencies act competitively (Yao et al., 2010). Because of that the study of decision-making during emergency response must incorporate research on organizational designs and relations.

In crises that span over organizational, jurisdictional, regional or national borders, decision-making is a coordinative activity and takes places in multiagency teams where the members may never have worked together before and where no obvious hierarchical relationships exist between team members and the team leader. Sharing information across borders may be a sensitive and sometimes politically loaded issue. Furthermore, decision-making will often have to include other parties such as advisors or interest groups. In these settings different actors may have very different perceptions of the threat and it can never be assumed that there will be consensus or even solidarity (Van Santen et al., 2009).

Comfort who has made several studies of response work after Hurricane Katrina notes that while organizational hierarchies are designed to decrease the transaction of information, they tend to introduce errors, biases, missing information and inadequate decision-making, and that this lack of independent decision-making in hierarchical structures can limit the responsive capacity of personnel. This may not be a problem in all scenarios but negative effects will increase with the size and scale of organizations and operations (Hardy & Comfort, 2015). A traditional way of handling crisis management has been a net-centric approach where a network of actors is commanded by a commander-in-chief. In these instances actual and correct information must be available and shared willingly and there must be a motivation to work toward common goals (van Santen et al., 2009) Experiences of actual crises however show lacking inter-organizational coordination and cooperation, that goals are often diverse and that information is not widely accessible. This type of context calls for a negotiation based coordination process in decision-making and the quality of decisions will depend on the attitude of team members towards the negotiation, the negotiation strategy and their

negotiation skills, something that should be counted into the mental model of each team member (Van Santen et al., 2009). This may have implications for how decision ought to be modelled and it also means that the use of a tool such as the IET must be envisioned in a complex organizational environment. In this environment, many sources of information may compete for the attention of decision-makers and integrating the IET will be a large task.

Issues such as the ones mentioned above border on socio-psychological factors that may also come into play both in within-group and between-group interactions. For example, the opposite of a common ground between different response groups is “groupthink” where harmony within the group is prioritized over critical assessment, and if the recognition-based decision-making of an incident commander means that inputs from various sources are not taken into account then that behavior may restrict their ability to redefine the situation (Njå & Rake, 2009). In these situations it is not inconceivable that a shared tool for information storage, processing and distribution such as the IET may help lower the social or organizational barriers between groups.

Another aspect of interactions that span the borders of organizations, regions and countries is the question of culture. It has been noted that multinational teams that work in coalition are often challenged by differences in their organizational structures, practices and rules of engagement (Masakowski, 2008). Cultural heritage, education and experience serve as a framework for sensemaking (Endsley & Garland, 2000) and culture can also affect how people relate to technology (Klein et al., 2007), for example how IT support in general or the underlying logic of a tool such as the IET is valued in a specific national context. These may be important issues to consider when the IET is implemented in a multi-organizational and/or multinational context.

5.7 Relevance for the tasks

This chapter has dealt with research on emergency response decision-making in situations where there may be wide-spread uncertainty around the situation, where pools of information may be over-flowing, where time and resources may be scarce and where the organizational, technical or geographical scope makes the situation complex. While these characteristics affect decision-making in many types of emergencies, the special purpose of the this chapter has been to determine whether research from the fields of HB and NDM holds equal validity for scenarios with far-reaching cascading effects.

5.7.1 Decisions, heuristics and biases

In complex scenarios, decision-making has been described as a distributed activity interwoven with other activities, deeply situated in the unique characteristics of the situation. Within the research field of Naturalistic Decision-making (NDM) studies of emergency response has been carried out for decades and this research has contributed in many ways to our understanding of how emergency response professionals make decisions under difficult circumstances. Studies of emergency responders have shown that the way they make decisions seldom aligns with formal models of decision-making. Instead of engaging in time-consuming analytical decision-making strategies they often use their experience in order to arrive at a satisfying decision quickly. Despite this they do not seem to be very prone to decision traps such as cognitive biases. As noted in the literature, the benefits of reduced cognitive effort and speed can often make naturalistic decision-making superior to formal procedures. One possible conclusion from this is that the IET should not lead to cumbersome technical management,

and that it may not always be wise to steer people into very strictly into sequential, rational modes of decision-making.

Even though studies have shown that experts often have a remarkable capacity to overcome limitations in time, information and resources, there is still room for the concept of bias in the discussion of first responder activities. Several of the heuristics identified by Kahneman and Tversky describe the flip-side of the smooth professional conduct described by the NDM community. Experts with long experience within their fields can typically make snap decisions with surprising efficiency, but no incident is identical to another and if preparations are insufficient, emergencies with cascading effects may very well approach the "low-validity" scenarios brought up by Kahneman and Klein (2009). However, whether a situation should be seen as low- or high-validity depends on the preconditions created for the response activities. A situation is only perceived as having a low level of predictability if there are not sufficient cues for interpretation, and enabling the perception of such cues is very much an issue of design, e.g. of organizations, processes, procedures, tools and training. The IET has been envisioned to have a role in both preparatory and operational phases of emergency response and if it can aid the perception and interpretation of cues for cascading effects then it could also increase the validity of the situation.

Skilled intuition will develop in an environment of sufficiently high validity and enough opportunity to learn the relevant cues and practice the skill (Kahneman & Klein, 2009). By providing more informative experiences a decision maker's expertise can be accelerated (Hoffman et al., 2009). Given that a tool such as the IET is designed around the needs of its users there may be number of ways in which it could support natural decision-making strategies. Based on the descriptions in the use cases of D4.3, the IET could help the collection and transfer of knowledge from experienced practitioners. This kind of transfer could then help responders during the preparatory phase to practice and to discuss possible future scenarios. RPD is cue driven and the tool could provide these cues for pattern matching, something that is perhaps more important than providing ready-made plans for action. As noted by Cohen, trying to anticipate every possible scenario tends to be either unmanageably complex or unrealistically simplified, and overplanning can suppress the variability that is necessary for learning, as well as the ability to innovate if the unexpected occurs (Klein et al., 1993). Lessons from the field studies of NDM indicate that first and foremost, technology should be used to support the understanding of states and events in the work environment.

5.7.2 Decision typologies

Decision-making "in the wild" has been examined and described using several different theoretical frameworks, but most decision-making models within the field of NDM share basic features of decision-making including the perception of cues in the environment, the formation of situation understanding in relation to certain goals relying heavily on experience, and a projection of likely future evolvements within the situation, all under the influence of situational constraints. The decisions and actions that follow then produce feedback which again can be used to reinforce the situation awareness of the decision-maker. Other related aspects or components of decision-making are planning, goal-setting, option evaluation, and updating, integrating and communicating/sharing of information.

Different scenarios may however impose very different constraints on decision-making and when any type of support is designed the underlying nature of the decision task in the particular context must be understood. Achieving SA could be more of a challenge in situations with cascading effects, because effects will carry over to domains that responders may not be

as familiar with or have insights in. For parties affected by cascading effects the creation of SA could also be a greater challenge because the cause of their problems may not be familiar or the cause will introduce disturbances that have not been anticipated.

Shared mental models of decision-makers may include knowledge of equipment and tools, understanding of the work including problems, goals and performance requirements, member/team/organizational characteristics including knowledge about the competencies, beliefs and habits of others, and knowledge about people's beliefs around appropriate processes and strategies. Shared mental models like these are likely to develop if there is a belief of shared ownership within the group, when self-evaluation and self-correction takes place, when there is an active sharing of information based on mutual respect, when team members are experienced in crisis management decision-making and when there is an everyday organizational context that also supports the work characteristics of emergency situations.

Some factors that may influence the success of decision-making (and the implementation of a support tool) are system capabilities, interface design, stress, workload, arousal, motivation, complexity, training, experience, culture, social dynamics such as group-effects, design of processes and the design of organizations. Some of these will be examined in more detail in other parts of this discussion.

5.7.3 Decision rationales in cascading effects situations

As Klein (2015) notes, the greatest challenge for decision-makers in professional settings is making sense of events and conditions. This sensemaking contributes to the base or rationale for decisions, and the literature gives many hints to factors that enable the formation of such a base.

The experience of professionals makes up an invaluable asset in emergency response, but since every situation will have some unique characteristics, which means that Responders must always strive to create harmony between experiences and new information. No information creates itself or exists independent of human interpretation and because of ever-changing circumstances, all information is subject to constant reinterpretation. NDM research has shown that high-risk operations in the real world rarely follow the neat logic of formal decision processes. Success depends more on the experience and adaptability of the human element than on computing power, but on the other hand, human capabilities depend on proper support. This poses a number of challenges when developing any kind of support tool for operations. In the process of decision-making, information on cascading effects could reinforce interpretational frames and help to guide both perception, sensemaking, option generation and the projection of possible future courses. When information can be transmitted simultaneously to different stake-holders, common ground is more likely to develop (Bergström et al., 2010). Different actors within an emergency may also have very different levels of knowledge about possible cascading effects, something that the IET could help even out. These prospects are strengthened by the fact that the IET is envisioned to have a role in collaborative training and strategic work, which is in accord with Comfort's (2007) notion that the formation of a common operational picture typically starts well before an actual event, during years of common training, shared experience and professional interaction among emergency response personnel.

5.7.3.1 Negotiation of decision rationales

Studies of real-world emergency decision-making give that creating a base for decisions is a collaborative process where many perspectives, competencies and cultures are included. Information cues may seem obvious and stable, but there is always room to interpret their meaning and their consequences for decision-making, such as when prioritizations must be made or in the selection of operational tactics. The process of working up to a decision through action and feedback is important for the quality of and belief in the final decision. Observations like these have spawned the notion of negotiation in the creation of rationales for decision-making. This process is collaborative in nature and must be taken into account when modelling emergency response decision-making, perhaps more so when cascading effects are added, because it lies in the nature of such emergencies that broader layers of people are involved.

It is important to realize that this negation of reality will also be true for the information managed within the IET. Biases stemming from heuristics such as representativeness, availability, imaginability, illusory correlation and confirmation are all related to the understanding and experiences of the individual, which means that in complex situations, many voices should be heard in order to counter bias. Cognitive frames for interpretation can be both productive and restrictive. Different categories of actors in an emergency context may have very different experiences, competencies and even geographical outlooks, and that will produce different perspectives on the task at hand. These differing interpretations could be seen as a resource, because nobody knows exactly what the future holds and in that way, different interpretations could be seen as a potential variability in decisions and actions. This creates an opportunity to include actors outside of the response organizations as assets in the work to mitigate an emergency. When relations to the public are discussed during the design of the IET, this discussion should not be limited to issues of passing out information. Instead an inclusive approach could be taken.

Having said that, because cognitive heuristics are typically associated with errors in probabilistic judgments, a tool such as the IET could provide support by introducing contextual information that otherwise runs the risk of being ignored (such as base rates). Providing information about possible cascading effects of actions or events could also help expand the “imaginability” or future evolvements in the scenario. On the other hand, if a data-rich narrative of a possible future chain-of-events is presented using the IET, such a narrative could become very dominating in the discourse about responder decisions. As it has been shown in research on decision-making, people tend to cling to strong narratives when creating mental models of a situation (Klein et al., 1993). This again is an issue of integration where it is important to make sure that there is a balance between the use of the tool and other information platforms in the decision-making context. The question whether the IET can support the reinterpretation or negotiation of decision rationales poses a challenge both for design and implementation.

Decision outcomes can also be affected by the organizational and cultural environment of implementation. Cultural heritage, education and experience serve as a framework for sensemaking and culture can also affect how people relate to technology, for example how IT support in general or the underlying logic of a tool such as the IET is valued in a specific national context. These may be important issues to consider when the IET is implemented in a multi-organizational and/or multinational context. In the larger collective of emergency responders (including NGOs and the public) the tool has to be accepted as a valid, shared source of information, and the information that it provides must also be trusted by all stake-

holders. Social dynamics could pose a problem here. For example, in-group bias is a commonly observed phenomenon even in professional settings, and if the IET were to be used by one group exclusively then information stemming from the use of that tool could be met with skepticism from other groups of stake-holders. Organizations have been observed to act competitively even in large-scale emergencies. On the other hand, if a tool is widely shared it can provide a common ground for decisions and help fuse the collective of response workers together, in the pursuit of shared goals. Reaching this situation is to some extent made more probable by the fact that the IET is envisioned to be part of training and preparations, because organizations and groups that have had the chance to build trust tend to be more cooperative in collaborative decision-making (Kapucu & Garayev, 2011). It is not inconceivable that a shared tool for information storage, processing and distribution such as the IET could then help lower the cultural or social barriers between groups and organizations.

Finally, what is apparent from experimental studies exposing cognitive bias is that these errors are largely provoked by situational factors in the working environment. If experiments can be designed to provoke bias then the flip-side is that response systems could be designed to allow users to avoid them, which is a good challenge when developing a tool like the IET.

5.7.4 Key decision points

Research within the field of NDM typically emphasizes the role of responder experiences over written rules and procedures. The kind of predictability associated with proceduralization and implied by terms such as “key decision points” is simply disaffirmed within many human-centered studies of emergency response, in acknowledgement to the dynamic nature of many emergencies. Instead of mainly relying on pre-made plans that never make a true match for the relative chaos of reality, this research instead focuses on how to support the adaptability of human actors. Experiences from accident analysis show that while the causes of an event seem easy to trace with the benefit of hindsight, every new situation appears to offer a unique cocktail of antecedents.

Even so, it may still be interesting to see whether there are aspects of emergencies stable enough to apply the label “key decision point”. One problem is the issue of cause and effect. Should we apply this label to events long before the actual event when decisions could have been made to prevent cascading effects, does the key point occur during the incident when action is taken to mitigate the propagation of cascading effects, or both? One suggestion might be that because the dynamic nature of the real world makes key points hard to predict, these points should rather be seen as a construction during the evolvement of an actual emergency. That would mean that key points are a matter of prioritization, that is, determining what action would have the largest impact on the spread of the emergency. If key points are viewed as operational constructs then efforts should primarily be made to support this construction, something that will be discussed further down.

On the other hand it can be noted that actual emergencies often display similar types of problems, such as issues of situation awareness, communication and collaboration. Cascading effects has to do with the spread of an emergency to neighboring systems, demanding the involvement of new categories of professionals. In this perspective, things like having the appropriate organizations, structures and technologies for cross-organizational or cross-border information-sharing may be the most effective means against cascading effects, and features like these are the results of strategic decision-making well before the actual event. This means that although a point in the evolvement of an emergency may be viewed as key, the key decisions that will steer future evolvement may have been made long ago.

6 Case studies

This chapter will present three cases that have been analyzed with regard to decision-making. This analysis has been carried out through a combination of bottom-up and top-down approaches, where analytical categories have been extracted both from the literature and from case description data. For each case a narrative is presented outlining the event in chronological order. Important decisions in the response work are then categorized and listed. The categories used for decisions have been selected through a combination of inputs from the literature and the cases themselves.

The three cases presented are the 2014 mudslide in Oso, USA (and hypothetical landslide in Séchilienne, France), 2005 bombings in London, UK and 2014 forest fire in Västmanland, Sweden. These cases have been selected due to their escalating nature and the appearance of cascading effects. They are also complex situations with several actors of different types involved which made it is possible to study the role of external actors as well as cross border effects.

6.1 2014 mudslide in Oso, USA and hypothetical landslide in Séchilienne, France

The source of virtually all of the information about the Oso Mudslide was The SR 530 Landslide Commission Final Report (Lombardo, K., et al., 2014), although some information also came from the cited newspaper reports. The information about the Séchilienne case was provided by INERIS for use in various parts of the CascEff project.

6.1.1 General description of event

In March 2014 an unstable hillside in Washington State, USA collapsed into a river valley covering the small town of Steelhead Haven and blocking the Stillaguamish river and road (SR 530) with 9 – 21 m of mud and debris. It covered an area of approximately 2.6 km2. In total, 43 people were killed, 4 people sustained serious injury, and 49 homes and other structures were destroyed. This event was given two names: Oso Mudslide, and SR 530 Landslide, the words mudslide and landslide are frequently interchanged in documentation of the incident.

There had been heavy rainfall in the region prior to the slide, along with earthquake and forest harvesting activities, all of which could have contributed to triggering the slide. There is a history of landslides in the area and it was not surprising that the hillside collapsed; the surprise was how fast the mud spread across the river valley and town (Winters, C., 2014) , which was estimated at less than 1 minute. The slide created a mud and debris dam that flooded the area upstream of the dam and threatened flash flooding of the area downstream of the dam if it catastrophically failed.

Air resources were available onsite within an hour of the initial landslide due to an unusual coincidence with Navy training operations. The command and control of the incident shifted from local responders to a regional level by the end of the first day. The governor declared a State of Emergency on the evening of the first day and state emergency response was activated the morning of the second day. President Obama issued a Federal Emergency Declaration on the third day, which allowed the use of additional resources and funding for recovery. More than 900 local, state and federal personnel and volunteers, contractors, families and neighbors were involved in the search, rescue, and recovery operations. The last victim was recovered in July 2014 and the reconstructed road was opened in September 2014.

In a similar situation, the case study of a hypothetical landslide occurring in the Sechilienne area of France was selected for analysis in another part of the CascEff project. The major difference is that no large scale landslide occurred in Sechilienne due to mitigation efforts. There are also some differences in possible cascading effects in the Sechilienne case due to industries, water treatment and power generating facilities along the river downstream of the landslide area. These differences illustrate the consequences of a few additional types of decisions and are included in the lists below identified by the mark (Séch).

6.1.2 Summary of decisions

The decisions (or lack of decisions) that were crucial to the outcome of this event are categorized in the following text to assist in the organization of the material. Decisions that could fall into more than one category have been placed in the category that best illustrates the use of the IET to prevent/minimize cascading effects.

6.1.2.1 Strategic/tactical

(Pre-event)

- Sufficient, sustainable funding and cross-jurisdictional coordination for emergency response has not been a priority among Washington State political decision-makers.
- Washington State has many known landslide areas but had decided not to provide the funding necessary to incorporate landslide hazard, risk, and vulnerability assessments consistently into land use planning. One could speculate that the reasons for inconsistent application of these safeguards are related to regional budget priorities.
- Since the Steelhead Haven area has a history of landslides and the town was known to be vulnerable, a plan to buy out the homeowners was considered but not implemented. Regional planners were more concerned about flooding than slides. In fact, new home construction permits were issued following a severe landslide in 2006 (Armstrong, K., 2014) .
- Over several decades decisions were made to mitigate the landslide hazard, including constructing berms along the edge of a previous slide, a revetment to protect the riverbank, a crib wall to protect fish from sediment, and diverting the riverbed. The results of all these efforts were destroyed by subsequent or concurrent sliding activity (Armstrong, K., 2014)3.
- (Séch) There is no alternative road to popular ski resorts upstream of the landslide area. The decision to develop plans for evacuation of people could minimize cascading effects related to detaining people for an indeterminate length of time in a severe mountainous environment, particularly if power is interrupted, e.g. medical, food, heat, etc.

(During the event)

- The procedure for activating the state-wide fire service during large scale non-fire incidents was unclear. In fact, legal counsel decided not to activate the state-wide fire service for this event when the request was made. Only local and regional firefighters were allowed to respond. In spite of numerous previous large landslides in which the state-wide fire service could provide valuable assistance, no decision was made to clarify and streamline the activation process.
- Seamless transitions of command and control during response to catastrophic events is needed; this requires a decision to develop a standard operating procedure for response organizations at all relevant levels.

- (Séch) Strategic decisions must include consideration of industries, water treatment facilities and power generation facilities downstream of the debris dam. The possible consequences of ignoring these vulnerable facilities include chemical contamination from industrial sources, the inability to treat drinking water, and interruption of power.

6.1.2.2 Situational awareness

(During the event)

- During the first phase of the landslide response, priority was given to rescuing victims using helicopters. The airspace thus became unsafe for other air resources to be used for reconnaissance and collection of information about the situation as a whole. This made situational awareness difficult for responders on the ground that were working to prevent catastrophic failure of the debris dam, which would have caused flash flooding downstream and possibly more casualties.

6.1.2.3 Communication

(Pre-event)

- The decision to plan redundant communication lines between communities would have improved strategic and tactic decisions, situational awareness, and resource allocation and logistics.

(During the event)

- Radio communication between responder organizations was difficult due to incompatible equipment. The decision to employ consistent radio frequencies among emergency responder organizations is a very important aspect of effective response to an emergency.
- A Joint Information Center was not established early enough to provide timely and accurate information to responders, emergency management organizations, and affected communities during the most critical phase of the response (rescuing survivors).

6.1.2.4 Resources

(Pre-event)

- No decision was made to develop a standard operating procedure for tracking, mobilizing, and demobilizing resources. Lack of knowledge of available resources and their location can inhibit response to disasters.
- No plan was in place to deal with multiple fatality events, which caused the capacity of local coroners and medical examiners to be overwhelmed. The decision to include this aspect of emergency response in the planning process is needed.
- (Séch) There is no alternative road to popular ski resorts upstream of the landslide area. The decision to develop plans for quickly deploying response equipment in this area could be vital to minimize losses.

(During the event)

- Resources were needed upstream of the debris dam to mitigate health and safety issues due to contaminated flood water and working in the mud. Considering the potential consequences, this would normally have been among the highest priorities in the response but the decision was made to delay deployment of a decontamination center for several days.

- The decision to use local volunteers to play a significant role in the response was made early in the response. This decision resulted in more focused searching for victims as well as aiding the prioritization and location of infrastructure to be restored. It also allowed local equipment to be used upstream of the debris dam, where it was logistically difficult to deploy equipment from responder organizations.

6.2 2005 bombings in London, UK

The source of virtually all of the information below was volume 1 of the Report of the 7 July Review Committee, published in three volumes by the Greater London Authority (2006), which includes a detailed timeline of the incident evolution and transcripts of hearings and interviews.

6.2.1 General description of event

On the morning of 7 July 2005, a bomb exploded on an eastbound Circle Line underground train in central London. Approximately one minute later, a second bomb exploded on a westbound Circle Line train, and another two minutes later a third bomb exploded on a southbound Piccadilly Line train. Almost one hour later, a fourth bomb exploded on a bus at Tavistock Square. In total, 56 people were killed, including the four bombers, and about 700 people were injured.

Chaos ensued during the initial moments after the bombs were detonated, with 999 calls reporting smoke and loud “bangs”. The first three bombs exploded underground, which inhibited the number of 999 calls to those people that were able to leave the trains and get to a location with mobile phone service. The passengers were also unable to communicate with the train drivers, thus prolonging the period of confusion and delaying focused efforts by first responders.

Many of the survivors reported that they did not know what was happening, or if first responders knew what had happened. They didn’t know if help was on the way or if a fire was coming down the tunnel toward them. They did not know if they should stay in the train or try to make their way to the surface. In many cases they were in shock and not thinking clearly.

When the news of the bombings became public, London’s telephone networks were inundated with calls due to people checking that their friends and family were safe. This congestion in the telephone networks caused problems with the emergency services that ranged from being an inconvenience to preventing communication between emergency managers and their control rooms.

The media contributed by informing the public of the incident and by communicating instructions, such as when it was deemed safe to leave the city centre and when the bus system and other services were restored, via advisory messages. A “Casualty Bureau” was set up to give people a means of finding information about missing persons; however, the telephone network was not sufficient for the volume of calls.

In the days and weeks after the bombings there were many people in need of psychological help to cope with the loss of friends and family. Survivors also needed help to recover from the trauma of the incident.

6.2.2 Summary of decisions

The decisions (or lack of decisions) that were crucial to the outcome of this event are categorized in the following text to assist in the organization of the material. Decisions that could fall into more than one category have been placed in the category that best illustrates the use of the IET to prevent/minimize cascading effects.

6.2.2.1 Strategic/tactical

(Pre-event)

- Emergency planners had worked for years to put in place effective plans to respond to a terrorist attack or other major or catastrophic incident in London. The decision to develop these plans was crucial in minimizing the losses resulting from the bombings.
- Prior to the bombings, emergency response vehicles did not have blue lights and were not allowed to use bus lanes while responding to emergencies. The decision to equip emergency vehicles with blue lights and give them access to bus lanes prior to the bombings would have helped them arrive at the incident more quickly, thus reducing the possibility of cascading effects related to activities immediately after the bombings occurred such as spread of potential contagions.

(During the event)

- Emergency responders were not deployed to the nearest train stations on either side of the bombed trains, thus victims that emerged from the tunnels at stations unattended by responders did not receive help immediately and some of them left the scene without receiving any help or providing contact information. A decision to send responders to both of the nearest train stations would have provided assistance to more victims, who may have been able to provide situational awareness to the responders.
- Each branch of emergency services (police, fire, ambulance) declared a major incident separately for each bomb location, which did not automatically alert the other branches. This fragmented procedure inhibited the establishment of a coordinated response. The Review Committee decided to recommend changes in this declaration procedure as a result of the bombing incident.

6.2.2.2 Situational awareness

(During the event)

- The emergency and transport services needed to quickly establish what had happened in order to develop a response strategy. Conversely, the passengers on the bombed trains were unable to contact emergency services or the train driver to tell them what had happened. This issue is included in the Communication section.

6.2.2.3 Communication

(Pre-event)

- The police were the only branch of emergency services that had radios that could operate underground. The inability of all emergency responders to communicate underground was known for at least 18 years but no decision had been made to correct the problem.
- The decision was not made to appoint a single person to act as spokesperson to the public throughout the incident, appointing such a person could have prevented confusion and minimized the consequences of untimely, conflicting, or inaccurate information. Some of

these consequences are related to knowing when it is safe to move around the city and when the bus service has been reinstated.

- The Casualty Bureau is the organization responsible for tracking victims of major incidents. Their telephone network was unable to handle the large number of inquiries about friends and family members as well as inquiries that were outside the scope of the Bureau. The Review Committee decided to recommend technological upgrades so that inquiries are handled outside the mobile phone network, thus alleviating congestion of the network and minimizing cascading effects associated with a dysfunctional mobile network. The upgrade, along with an additional public awareness program would also inform the public about the scope of the Casualty Bureau's functions.

(During the event)

- Many of the trains did not have a mechanism by which passengers and train drivers could communicate. The decision to fit all trains with this capability as quickly as possible was made as a result of this incident. Communication from the passengers (and train driver) can help the responders understand what happened, develop response strategies, and instruct the passengers.
- Communication between the train drivers and the London Underground line controllers was generally unreliable and was inoperable for the three bombed trains. Lack of communication prevented emergency responders from making rapid assessments of the situation. The decision to assign a low priority to communication system upgrades and maintenance led to delays in forming response strategies, poor situational awareness, and allowed victims to disappear without getting help.
- The mobile telephone system became overloaded during the incident. The emergency services that did not have functioning radios relied on their mobile phones for communication between field personnel and the command and control center. The decision not to activate a system that restricts access to the mobile phone network was made because key response personnel did not have mobile phones with the technology to gain access to the restricted network, also there was concern that the public would panic. However, the system was activated without proper approval at one of the bomb sites.
- Lack of communication between ambulances, responders at the bomb sites, and hospitals caused delays in transporting victims to hospitals. The ambulances did not always know which hospitals were capable of receiving victims. In one case, a hospital that was not listed as a possible receiver but was located near one of the bomb sites decided to set up a "field hospital" to do triage and care for the most seriously injured. This decision may have helped prevent further escalation of the incident.

6.2.2.4 Resources

(Pre-event)

- The decision to plan for establishment of survivor reception centers at all major incidents could result in better collection of information about the victims and also could provide information that is helpful for emergency responder situational awareness.

(During the event)

- There were inconsistent, uncoordinated, or nonexistent efforts to collect and collate information from the victims that were able to walk away from the bomb sites. Resources were focused on caring for the most seriously injured victims, which is of course understandable. The decision not to set up a mechanism by which at least contact

information was collected for all victims led to problems for the care of survivors later, establishing missing persons, and may also have affected the police investigation.

6.3 2014 forest fire in Västmanland, Sweden

In July 31th 2014 a forest fire broke out in the Swedish province of Västmanland (Justitiedepartementet, 2015). The fire developed into the largest Swedish forest fire in modern time. The response operation continues until the 11th of September when the rescue operation officially was terminated by the incident commander (Uhr et al., 2015, p. 12).

6.3.1 General description of event

6.3.1.1 Thursday the 31th of July

A forest machine operator was preparing the ground when he discovered a fire behind his machine. He tried to extinguish it himself, and also called the dispatch center, SOS Alarm, to alert the rescue service. The fire area was about then 30 x 30 meter (Justitiedepartementet, 2015; Länstyrelsen i Västmanlands län, 2014). The alarm was received at SOS Alarm at 13:29 saying that a forest fire had occurred at a clear cut northeast to Seglingsberg in the municipality of Surahammar (Justitiedepartementet, 2015). The commander at Mälardalen Fire and Rescue Services (MBR) who was listening to the call from SOS Alarm, mentioned to the SOS Alarm operator to alarm forces as planned for forest fires (Justitiedepartementet, 2015, p. 40).

Problems with the navigators and thus problems with finding the place of the fire resulted in that the rescue service was about 40 minutes delayed to the fire scene. When the rescue service finally arrived the fire had spread and they assessed the fire to be 400 x 600 meter (Justitiedepartementet, 2015). The fire spread quickly during Thursday afternoon and in the evening the fire included an area of 100-150 hectare (Justitiedepartementet, 2015, p. 46)

SOS Alarm also activated the national information telephone number 113 13 to receive public information and questions (Justitiedepartementet, 2015, p. 42).

During the afternoon the incident commander assessed that they needed more assistance and SOS Alarm alerted other stations. During the day also the fire service from Sala-Heby became involved since the fire spread into the municipality Sala. The involvement of several rescue service organizations highlights the need for cross border cooperation. In the evening MBR assessed that the fire mainly was in the municipality of Sala and thus did not affect their area and reduced it forces and the command over the response was left to Sala-Heby. But later during the evening the intensity increased and resources from MBR was again intensified (Justitiedepartementet, 2015, p. 45).

In the evening water bombing of the fire with a private helicopter was initiated ordered by the rescue service Sala-Heby.

Late Thursday afternoon one of Swedish defense forces helicopter arrived at the fire scene. They accidental flew over the area on their way home and went down to talk to the rescue service due to that the big fire. The incident commander at MBR got information of how to contact and request support from the defence forces. At the time he did not seem to be interested in flying over the area or in the pictures that the helicopter had taken. The helicopter left the area (Justitiedepartementet, 2015, pp. 45-46). Later that evening a request for support was left to the Swedish defense force by Sala-Heby. The helicopter was sent back

to the fire scene and could during the Friday start helping with water bombing (Justitiedepartementet, 2015).

During the day there was no comprehensive situation awareness of fire (Justitiedepartementet, 2015, p. 46). In addition, in practice the response was managed as two separate responses, one from each of the two involved rescue services (Uhr et al., 2015, p. 7). This identifies the challenges with actually having cross-border cooperation. During the cause of event several actors external to the rescue service organizations, such as this private helicopter, became involved in the response (Justitiedepartementet, 2015, p. 45; MSB, 2015, p. 37). Except for the rescue service personnel (around 30 persons), external actors such as a forest company and some private citizens was involved in the response (Justitiedepartementet, 2015, p. 46).

During the evening the Duty Officer (TiB) from the County Administrative Boards of both Uppsala and Västmanland was contacted all according to the dispatch center SOS Alarm routines (Justitiedepartementet, 2015, pp. 42-43).

6.3.1.2 Friday the 1st of August

During the Friday Sala-Heby rescue service was in command of the response. But in practice the response was still conducted as two separate responses with different commands and organizations. There was no structured coordination between the two responses (Justitiedepartementet, 2015, p. 48; Uhr et al., 2015, p. 7), which as mentioned earlier, points at the challenges with cross-border cooperation. During Friday there were no common operational picture and there were no “picture” of the whole fire area. During the evening a reconnaissance from the air but due to the smoke it was impossible get an overview (Justitiedepartementet, 2015, p. 48).

During the evening, management support with external officers and a commander vehicle with operator came to the scene from other parts of Sweden (Uhr et al., 2015, p. 7). As more external actors arrived, the response organization gets more and more complex and thus cooperation over the boarders gets more important as well as more challenging.

The fire's intensity increased during Friday afternoon. The firefighters had problems keeping their boundary lines and were, in some places, forced to retreat. During the day it was reported that there was a lack of material for firefighting and that they had problems in getting out food and drink to the people working at the fire front (Justitiedepartementet, 2015, p. 47). During the Friday they requested forest-fire modules in containers from the Swedish Civil Contingencies Agency’s (MSB) depot (Justitiedepartementet, 2015, p. 47).

The fire fighting was performed with both firefighting at the ground and with helicopter. On the ground the rescue service used water cannons from their fire trucks and manure barrels. In addition, forest companies and landowners participated in the response. As the fire developed during the day more rescue services became involved. From the air private helicopter worked with water bombing from early Friday morning. During the day more helicopters arrived, e.g. from the Swedish defense force, and started to work with water bombing (Justitiedepartementet, 2015, p. 47).

During the evening the Duty Officer (TIB) from the County Administrative Board of Västmanland contacted the rescue service incident commanders and offered help with cooperation in the response. But the incident commanders declined (Justitiedepartementet, 2015, p. 48).

6.3.1.3 Saturday the 2nd of August

On Saturday morning the wind direction was changed and the fire spread in new directions (Justitiedepartementet, 2015, p. 48). It was still unclear who have the role as incident commander but at lunch time it was decided that the Sala-Heby fire chief takes the role. But there are still two separate support staff organizations (Justitiedepartementet, 2015, p. 50; Uhr et al., 2015, p. 7). The response organizations thus still have difficulties with cross-border cooperation. In the evening the extent of the fire area had more than doubled (Justitiedepartementet, 2015, p. 49). Even if the picture of the situation becomes better during the day there is still no common operational picture (Justitiedepartementet, 2015, p. 50; Uhr et al., 2015, pp. 7-8). In the evening the fire included an area of 2000 hectare (Justitiedepartementet, 2015, p. 50).

The response to the fire continued during the day with around 70 firefighters. Water bombing with helicopter continued. The personnel working with the response were describes as tired and during the day resources from close by rescue services arrived. Further, during Saturday resources from the military and Home Guard as well as the Voluntary Resource Group are requested by the rescue service (Justitiedepartementet, 2015, p. 49; Uhr et al., 2015, p. 8). During the day the rescue service also start up the cooperation with the police (Uhr et al., 2015, p. 7).

During the day a first General Decision (GD) is taken was taken (Uhr et al., 2015, p. 7).

During the evening they requested two forest-fire modules in containers from the MSB's depot (Justitiedepartementet, 2015, p. 49)

Also this evening the Duty Officer (TIB) from the County Administrative Board of and Västmanland is in contact with the incident commanders and offered help. The help is still declined. They describe the situation as difficult but hopeful (Justitiedepartementet, 2015, p. 50; Uhr et al., 2015, p. 8).

6.3.1.4 Sunday the 3rd of August

The firefighting operation continues during Sunday. The conditions are better with less wind and more humidity in the air (Justitiedepartementet, 2015, p. 50). Still, the situation for the response personnel becomes harder since trees had fallen over roads. In addition, the available resources were insufficient. In the evening the fire included an area of 2700 hectare and around 100 fire men and other persons was involved.

Still there is no common operational picture of the whole situation. In addition, since more and more actors are getting involved the need for more cooperation increases. A common command post is created outside the conference facility Ramnäs (Justitiedepartementet, 2015, p. 51). But the work is still done in the incident command buss in the woods. There are for the moment three different support staff groups. The work is thus not performed as a single response (Uhr et al., 2015, p. 8) and again points at the difficulties with cross border cooperation.

During the day more actors become involved. For example, resources from the military and the Home Guard (Justitiedepartementet, 2015, p. 51).

The incident commander request special forest-fire aeroplanes with high capacity via EU Disaster Coordination (from Italy and France) through MSB, thus a request for external resources. They become delayed due to bad weather and are not used until Wednesday the 6th of August (Länstyrelsen i Västmanlands län, 2014, p. 10; Uhr et al., 2015, p. 8).

During Saturday evening the County Administrative Board of Västmanland decides to start up their crisis response organization. From Sunday they also took the responsibility for coordination of information. In addition, during the evening the County Administrative Board of Västmanland decided to hold the first collaboration conference in U-Sam which consists of different actors in the county (Uhr et al., 2015, p. 8). This is an initiative to affect the interagency or cross border cooperation.

6.3.1.5 Monday the 4th of August

The Monday is a warm day with wind and the fire spread quickly (Länstyrelsen i Västmanlands län, 2014, p. 10). During the day one person is killed and one badly hurt (Uhr et al., 2015, p. 8). Monday evening the circumference of the fire was 60 kilometers and the situation was described as critical and around 200 people were involved in the response (Justitiedepartementet, 2015, p. 54-55).

The incident command post moved during the morning in to the Ramnäs conference center and a new structure and management organization was created (Uhr et al., 2015, p. 9). More people were also involved in the staff (Justitiedepartementet, 2015, p. 55).

During the afternoon and the evening about 1000 persons had to be evacuated. In addition, some people were forced to directly escape from the fire (Länstyrelsen i Västmanlands län, 2014, p. 10). In one of the villages Gammelby with 100 inhabitants the evacuation was needed so quickly that there was no time for using the IPA system (Important Public Announcement) instead firemen and policemen perform the evacuation directly. In other places the evacuation is initiated with the IPA system (Länstyrelsen i Västmanlands län, 2014, p. 11). The fire also threated Norberg and they prepare for a possible big evacuation of the 4500 inhabitants. This was done by placing 20 busses in Norberg (Länstyrelsen i Västmanlands län, 2014, p. 10). This evacuation was never implemented. Still there was confusion Norberg if they should evacuate or not. Some part of media interpreted the preparation as it was an ordered evacuation and the wrong message thus went out in media (Asp et al., 2015, p. 87). In addition, there were also extensive evacuations of animals within the area performed by voluntary resources (Justitiedepartementet, 2015, p. 54).

Due to the intensity of the operation there was a need for additional personal resources. Rescue services from other parts of Sweden were thus involved to staff the response organization. In addition, authorities, the military, voluntary actors and forest owners are involved in the response (Uhr et al., 2015, p. 9). The response thus consisted of several different actors.

In the evening a jointly meeting was done between the three involved rescue services (four municipalities) with the aim of taking a comprehensive approach of the response. During the evening the involved rescue services explicitly ask the County Administrative Board to take over the responsibility of the response (Justitiedepartementet, 2015, p. 56; Uhr et al., 2015, p. 9).

6.3.1.6 Tuesday the 5th of August

Tuesdays is described as a turning point of the fire (Länstyrelsen i Västmanlands län, 2014, p. 17). There were less wind and more humidity in the air. There was also some rain during the day (MSB, 2015, p. 49).

Emergency response was taken over by the County Administrative Board at 10:15. Lars-Göran Uddholm becomes the incident commander for the response (Uhr et al., 2015, p. 10). A Joint

Rescue Coordination Center is created in Ramnäs including different involved actors. Initially the focus is on the response of the fire and its immediate consequences (Uhr et al., 2015, p. 11). This initiative was a way to overcome the challenges with cross border cooperation.

6.3.1.7 Wednesday the 6th of August

During the day the fire does not spread. The weather conditions had become much better and it was raining (Länstyrelsen i Västmanlands län, 2014, p. 17; Uhr et al., 2015, p. 11).

6.3.1.8 Monday the 11th of August

During Monday it rains a lot and the response organization finally manage to get control of the fire (Länstyrelsen i Västmanlands län, 2014, p. 17).

6.3.1.9 Thursday the 11th of September

The rescue operation continues until the 11th of September when the rescue operation officially was terminated by the incident commander (Uhr et al., 2015, p. 12).

6.3.2 Summary of decisions

The decisions (or lack of decisions) that were crucial to the outcome of this event are categorized in the following text to assist in the organization of the material. Decisions that could fall into more than one category have been placed in the category that best illustrates the use of the IET to prevent/minimize cascading effects.

6.3.2.1 Strategic/tactical

- The rescue service MBR assessed that the fire mainly was in the municipality of Sala and thus did not affect their area and reduced it forces. But later during the evening the intensity increased and resources from MBR was again intensified.
- Water bombing of the fire with helicopter started. This was done by a private helicopter ordered by Sala-Heby.
- A first General Decision (GD) is taken was taken.
- The Duty Officer (TIB) from the County Administrative Board of Västmanland contacted the fire services incident commanders and offered help with cooperation in the response. But the incident commanders declined.
- A common command post is created outside the conference facility Ramnäs. But the work is still done in the incident command buss in the woods. There are at that time three support staff organisations one in Ramnäs, one for Sala-Heby and one for MBR. The work is thus not performed as a single response.
- About 1000 persons had to be evacuated. In addition, some people were forced to directly escape from the fire. In one of the villages Gammelby with 100 inhabitants the evacuation was needed so quickly that there was no time for using the IPA system (Important Public Announcement) instead firemen and policemen perform the evacuation directly. In other places the evacuation is initiated with The IPA system.
- The fire also threated Norberg and they prepare for a possible big evacuation of the 4500 inhabitants. This is done by placing 20 busses in Norberg. This evacuation was never implemented.
- Extensive evacuations of animals occurred within the area. This was done by voluntary resources.

- The incident command post moved in to the Ramnäs conference center and a new structure and management organization was created. More people were also involved in the staff.
- The involved rescue services explicitly ask the County Administrative Board to take over the responsibility of the response.
- At 10:15 a.m. Tuesday the 5th of August the emergency response was taken over by the County Administrative Board. Lars-Göran Uddholm becomes the incident commander for the response. A Joint Rescue Coordination Center is created in Ramnäs including different involved actors. Initially the focus is on the response of the fire and its immediate consequences.
- The rescue operation continues until the 11th of September when the rescue operation officially was terminated by the incident commander.

6.3.2.2 Situational awareness

- During the first day of the incidents, as well as some of the following, there was no comprehensive situation awareness of fire. Which men that no comprehensive situational awareness of the fire existed

6.3.2.3 Communication

- The dispatch center SOS Alarm is activated the national information telephone number 113 13 to receive public information and questions. This thus increased the possibility to give public information and answer questions

6.3.2.4 Resources

- Late Thursday afternoon one of Swedish defence forces helicopter arrived. They accidental flew over the area on their way home and went down to talk to the rescue service due to that the big fire. The incident commander from MBR got information on how to request resources from the defence force. Further, he did not seem to be interested in flying over the area and the helicopter continues its trip home. Later that evening a request for support was left to the Swedish defence force. A helicopter was sent to the fire scene and could during the Friday start helping with water bombing.
- During the Friday they realize that they needed more resources and the emergency service requested forest-fire modules in containers from the MSB's depot
- Resources from the military and the Home Guard become involved in the response.
- The incident commander request special forest-fire aeroplanes with high capacity via EU Disaster Coordination (from Italy and France) through MSB. They become delayed due to bad weather and are not used until Wednesday the 6th of August.
- Due to the intensity of the operation there was a need for additional personal resources. Rescue services from other parts of Sweden were thus involved to staff the response organisation. In addition, authorities, the military, voluntary actors and forest owners are involved in the response.

6.4 Appendix 1

The study reported in the appendix demonstrates that the case of an initiator having multiple high-risk consequences associated with evacuation safety of citizens can be investigated with evacuation modelling tools. The work represents an example of an effective use of evacuation modelling tools for assisting decision-making in case of incidents of different complexities, including cases in which escalating and cascading effects take place. For instance, the

possibilities of using evacuation modelling for the evaluation of possible countermeasures to an evacuation incident and how an effective decision-making of first responders can positively affect evacuation safety. The work exemplifies this issue for the specific case of a music festival scenario, but it is possible to extend the same principle to a variety of contexts in which large-scale evacuation may occur.

A more detailed discussion of the modelling of the incident and the conclusions from the modelling is included in Appendix 1.

6.5 Relevance for the task

There are many descriptions of the three studied emergency scenarios and it is thus not possible, as in every situation, to describe one true story of the responses. A description and discussion of an emergency situation, as in this report made retrospectively, tends to be done with hindsight. It is easy to say that a decision maker should have taken another decision. Further, in an emergency situation there are an endless number of decisions and the process of selecting which decision to analyze is an act of power.

6.5.1 Making sense of the situation

As mentioned, to make sense of an event and its conditions is the greatest challenge for a decision maker. Decisions will be based on the decision-makers interpretation of the new information and are always based on the person's earlier experience. This also makes it hard in new unfamiliar situations or in situations where you have very little information. One example on this is the London bombing were the survivors describe difficulties in understanding what actually had happened.

As described, decision making is seldom done with formal models of decision making. Instead the strategy is to use ones experience to arrive at a decision which is a much faster process. Except earlier experience that a decision maker (or sometimes a group of decision makers) has (including the experience him/her have from a preparedness process) different types of preparedness plans, SOPs are commonly lifted as important in an emergency situation. In London they, before the bombing, had prepared for exactly terror attacks and thus there existed response plans for terror attacks. But it is seldom that one is so lucky that what one had prepared for actually happens, at least when creating plans for specific scenarios.

Experience of one situation affect the response to the next, at the same time as one situation never is the same as the next one. Thus the way decision-making work in practices can also lead to "wrong decisions", at least when you look at the decision in hindsight. Similar, as discussed earlier cognitive frames for interpretation can be both productive and restrictive. For example a condition that possibly affected the response of the Västmanland forest fire was that a number of small forest fires had been extinguished without major problems earlier in the week. As previous experience is an important aspect and affect how one interprets a situation, the previous easy extinguished forest fires probably affected the rescue services understanding when they tried to make sense of the new situation.

What characterizes almost every emergency situation, and also is evident in the three studied cases, is the lack of information as well as constrains both when it comes to time and resources. Information of the situation and thus also knowledge gaps affect how people understand and interpret the situation and thus also their actions. In for example the London bombing there were in the beginning clearly a lack of information of what actually had happened. Different constrains further limits their possible actions. For example in the

Västmanland case the rescue service several time during the response reported that they did not have enough resources.

6.5.2 Responding to a cascading event

All three studied cases can be described as complex systems with emergent non-linear flows and interactions. The situations can thus be described as major unfolding cascading events that also are affected both by the decisions people make and by conditions that no one can affect.

Conditions that no one can affect might have major effect on an event. For example in the Västmanland forest fire the fact that it was a warm summer and the ground was dry, thus there was a great fire risk. Further, when the fire had started the development and spreading was probably also affected by the fact that the ground was dry. In the end the rain was a major cause for that they actually manage to control the fire. Similar, in the Oso mudslide the ground had problems with stability and in combination with heavy rainfall and earthquake the mudslide occurred.

The three studied situations also show the difficulties with planning for emergencies since it is impossible to know everything that will happen in the future. Further, things that coincidently occur during the situation can have a major impact, both good and bad. As Quarantelli (1997) argues planning should focus on general principles rather than specific details. In the Oso mudslide, for example, it is described that air resources were available much faster than expected due to a Navy training operation that coincidently occurred nearby at the time for the mudslide.

In an emergency situation it is not uncommon that one needs to prioritize. Prioritizing is seldom easy and as decisions seldom are done based on formal models prioritizing may sometimes, in hindsight, be accused of not being thought through. In for example the Oso mudslide they prioritize during the first phase of the response to rescue victims using helicopters. This made the airspace unsafe for other tasks, that one could argue that they also should have done, such as collecting information about the situation as a whole. Similar, in the London bombing case they prioritized their resources to caring for injured victims. This meant that for example there were no efforts to collect and collate information about the situation from other not injured victims when they walked away from the bomb site.

6.5.3 Several actors and cross border effects

Another aspect in emergency situations is that many different actors might be involved. This commonly led to challenges with interagency or cross border cooperation, especially in the cases there the different actors have not worked together before.

In for example the Oso mudslide more than 900 persons were involved in the search and rescue, and recovery operations. This was local, state, federal personnel as well as volunteers, contractors, families and neighbors. In the Västmanland forest fire, except for the emergency services, also for example the police, the military, forestry companies, volunteers and private citizens were involved. In addition, special forest-fire airplanes from Italy and France with Italian/French pilots were used. When studying the different situations it is thus possible to find aspects that affected the needed cross border cooperation's. For example one aspect that is pointed out in the literature about the forest fire is that it during the first days the response was run as two parallel responses, one in each municipality. Not until the county administrative board the 5th of August took over the response, six days after it started, one

incident commander had the responsibility for the whole rescue response. Another example of a cross border problem was that in the London bombing each branch of emergency service declared major incident separately but they did not automatically alert the others. This of course affected the possibility to establish a coordinated response.

6.5.4 Key decision points

Even if a decision is made at a specific point in time they are always affected as well as constrained by what happened earlier, even long before the incident occurred. Further, in the time of a decision it is not possible for the decision maker to know exactly how the specific decision will affect the cascading event.

One decision that can be interpreted as a very essential one in the Västmanland forest fire and thus a key point is when the County Administrative Board decided to take over the responsibility for the fire and rescue operation according to the Swedish Civil Protection Act (SFS 2003:778) at the 5th of August. The County Administrative Board also decided to appoint an incident commander and a deputy rescue leader for the forest fire, with responsibility for the management and organization of the operation. This decision resulted in that the response went from two parallel response operation to one single response, at least on the overall level.

6.5.5 Information sharing

In a situation with many involved actors in the response and that also affect the surrounding community information sharing is always an essential part. It is also a difficult part and one that commonly is brought up in evaluations as a problem. The question is who needs what information.

In the London bombing it is reported that they had problems with the communication network. As in many other emergency situation people start calling their loved ones to either tell them that they are okay or hear if they are okay. The mobile telephone system thus became overloaded. Another problem with the communication infrastructure that came up was that only the police had radios that worked underground. Also during the Oso mudslide response problems with communication was reported. For example there was incompatible equipment which made the radio communication between different actors difficult. Also in evaluations of the Västmanland forest fire they describe problems with communication infrastructure as one reason for shortcomings in the communication within the response organization. For example the communication infrastructure did not manage the large load and that there was poor coverage out in the woods. Locality of the decision-making is thus an important aspect.

In the Västmanland forest fire a Joint Rescue Coordination Center including different involved actors was not created until the County Administrative Board took over the response. In the Oso Mudslide it is argued that a Joint Information Center was not established early enough to provide timely and accurate information to responders, emergency management organizations, and affected communities during the most critical phase of the response (rescuing survivors).

Shortcomings when it comes to informing the public about the emergency are commonly an aspect that is brought up in emergency evaluations. But also the possibility for the victims to communicate with for example the emergency service is important.

In the London bombing the passenger in the trains was not able to communicate with the train drivers which prolonged the period of confusion. Further, the passenger could not contact the

emergency service to inform what had happened which meant that it took longer time for them to get a picture of the situation. Also the other way around, there were problems with informing the affected individuals about the situation due to the location. So a lot of the victims did not know for example what had happened, if help were on the way, if the fire was coming down the tunnel towards them, if they should stay in the train or try to make their way to the surface. In the London bombing media was also used to inform the public and instructing them on how to behave, which seems too worked out quite well.

In the Västmanland forest fire it is reported that there were confusion in the communication if the citizens in Norberg should evacuate or not. It is described that the incident commander recommended that they who could should leave Norberg and that others should prepare for a possible evacuation. But it was a recommendation not official order for evacuation. Some part of media interpreted this as it was an ordered evacuation and the wrong message thus went out in media.

7 Conclusions

This report has examined different sources in order to describe what characterizes decision-making in emergencies with cascading effects. Many of the traits associated with large-scale emergencies also seem to hold true for cascading effect scenarios i.e. a certain level of complexity, time pressure and uncertainty. All of these features were observed in all of the included cases. However, this report has argued that such attributes, as well as other similar descriptions e.g. Kahneman and Kleins low- versus high-validity environments, are largely dependent on the design of organizations, procedures, support tools, training and other issues of management. That is, whether an event is deemed as complex, stressful or difficult to grasp depends both on responder experiences and their ability to make sense of incoming information, an ability that in turn depends on the support that they are given.

7.1 Implications for the modelling task

A model of decision-making has to take into account that emergencies with cascading effects will involve many groups of actors such as responders, NGOs, political actors and the public. These persons may be distributed both organizationally and geographically, placing certain demands on collaboration and communication.

7.1.1 Response activities and performance shaping factors

Basic features of decision-making taken from the literature include the perception of cues in the environment, the formation of situation understanding in relation to certain goals relying heavily on experience, and a projection of likely future evolvements within the situation, all under the influence of situational constraints. The decisions and actions that follow then produce feedback which again can be used to reinforce the situation awareness of the decision-maker.

Some aspects or components of decision-making from the literature that could be used as an inspiration for the modelling task are monitoring, perceiving, sensemaking, projecting, planning, goal-setting, option evaluation, prioritization, trial-and-error (action/feedback), and updating/integrating/communicating/sharing of information.

Examples of factors that may influence the success of decision-making (and the implementation of a support tool) are system capabilities, interface design, stress, workload, arousal, motivation, complexity, training, experience, culture, social dynamics such as group-

effects, design of processes and the design of organizations. If factors such as these are integrated into the model of D3.1, that could aid in discussions about potential vulnerabilities and risks.

For parties affected by cascading effects the creation of SA could also be a greater challenge because the cause of their problems may not be familiar or the cause will introduce disturbances that have not been anticipated.

7.1.2 Rationales for decision-making

A model of decision-making in emergency situations with cascading effects should reflect the fact that creating rationales for decision-making is a collaborative effort engaging many groups in a negotiation over facts, decisions and actions. Creating this common ground for decision-making is particularly hard in the case of cascading effects because such emergencies likely involve groups that have little experience of working together. Shared mental models of decision-makers may include knowledge of equipment and tools, understanding of the work including problems, goals and performance requirements, member/team/organizational characteristics including knowledge about the competencies, beliefs and habits of others, and knowledge about people's beliefs around appropriate processes and strategies.

7.1.3 Key decision points

Experiences from accident analysis show that while the causes of an event seem easy to trace with the benefit of hindsight, every new situation appears to offer a unique cocktail of antecedents. It may be questioned where in the chain-of-events, spanning from well before the actual emergency, the key decision point should be placed. Findings from both cases and the literature suggests that key points often appear when communications and collaborations have to be initiated with neighboring systems and where the necessary structures for this are not in place. One suggestion might be that because the dynamic nature of the real world makes key points hard to predict, these points should rather be seen as a construction during the evolvement of an actual emergency. If key points are viewed as operational constructs then efforts should primarily be made to support this construction, which means that the IET must also be able to act as a powerful operational tool.

7.2 Implications for further developments of the IET

Findings around possible developments of the IET are based on the conclusion that success in emergency situations depends more on the experience and adaptability of the human element than on computing power. On the other hand, human capabilities depend on proper support. If a tool such as the IET is designed closely to user needs then it may have a significant impact on society's ability to respond to cascading effects. As noted in the literature, the benefits of reduced cognitive effort and speed can often make naturalistic decision-making superior to formal procedures. One possible conclusion from this is that the IET should not lead to cumbersome technical management, and that it may not always be wise to steer people into very strictly into sequential, rational modes of decision-making.

Cascading effects has to do with the spread of an emergency to neighboring systems, demanding the involvement of new categories of professionals. In this perspective, things like having the appropriate organizations, structures and technologies for cross-organizational or cross-border information-sharing may be the most effective means against cascading effects, and features like these are the results of strategic decision-making well before the actual

event. It is noted that all countries described in chapter 4 have procedures for escalating response, but preconditions for escalation are often associated with the emergency being "large-scale". Cascading effects may also result from emergencies smaller in scale. Whether the procedures for escalation of these countries are sensitive enough to cascades could perhaps be investigated further. A tool such as the IET could have a role to play in such a task.

7.2.1 Construction of decision rationales

Building a base for decisions is a process of situation assessment and lessons from field studies within the field of NDM indicate that first and foremost, technology should be used to support this situation awareness. Achieving SA could be more of a challenge in situations with cascading effects, because effects will carry over to domains that responders may not be as familiar with or have insights in. This was apparent particularly in the cases of the 2005 bombings in London, UK and the 2014 wildfire in Västmanland, Sweden. A major cause of this were the breakdowns of different technical systems for communication.

Cascading effects scenarios mean that more and diverse groups will be involved, placing larger demands on cohesion and negotiation. Biases stemming from heuristics such as representativeness, availability, imaginability, illusory correlation and confirmation are all related to the understanding and experiences of the individual, which means that in complex situations, many voices should be heard in order to counter bias. Different categories of actors in an emergency context may have very different experiences, competencies and even geographical outlooks, and that will produce different perspectives on the task at hand. Because nobody knows exactly what the future holds, different interpretations could be seen as a potential variability in decisions and actions. It is important to realize that the information managed within the IET will likely also be subject to this kind of negotiation.

Moreover, narratives are powerful. If a data-rich narrative of a possible future chain-of-events is presented using the IET, such an information source could become very dominating in the discourse about responder decisions. This again is an issue of integration where it is important to make sure that there is a balance between the use of the tool and other information platforms in the decision-making context. Is implementation is successful, information on cascading effects could reinforce interpretational frames and help to guide both perception, sensemaking, option generation and the projection of possible future courses. That cognitive frames may restrict the effectiveness of responder strategies was demonstrated in the Västmanland case.

Discussions within this report have indicated that predictability is perhaps more inherent in the design of response structures than in emergencies themselves. A situation is only perceived as having a low level of predictability if there are not sufficient cues for interpretation, and enabling the perception of such cues is very much an issue of design, e.g. of organizations, processes, procedures, tools and training. The IET has been envisioned to have a role in both preparatory and operational phases of emergency response and if it can aid the perception and interpretation of cues for cascading effects then it could also increase the validity of the situation. In Appendix A, an applied study is presented of how evacuation modelling tools can be used to assist decision-making in case of emergencies with cascading effects.

Given that a tool such as the IET is designed around the needs of its users there may be number of ways in which it could support natural decision-making strategies. RPD is cue driven and the tool could provide these cues for pattern matching, something that is perhaps more important than providing ready-made plans for action. because cognitive heuristics are typically associated with errors in probabilistic judgments, a tool such as the IET could provide

support by introducing contextual information that otherwise runs the risk of being ignored (such as base rates). Moreover, based on the descriptions in the use cases of D4.3, the IET could help the collection and transfer of knowledge from experienced practitioners. Different actors within an emergency may also have very different levels of knowledge about possible cascading effects, something that the IET could help even out. This kind of transfer could then help responders during the preparatory phase to practice and to discuss possible future scenarios.

One major difficulty with respect to cascading effects is when there is a need to upscale emergency response. The fire in Västmanland developed from a small firefighting effort to the largest forest fire in Swedish history and escalations of emergency response appear to have been carried out late. In order to grasp an escalation like this, responders must be able to interpret the available cues for possible cascades. The prospects for this are strengthened by the fact that the IET is envisioned to have a role in collaborative training and strategic work, which is in accord with Comfort's (2007) notion that the formation of a common operational picture typically starts well before an actual event, during years of common training, shared experience and professional interaction among emergency response personnel. Providing information about possible cascading effects of actions or events could also help expand the "imaginability" or future evolvements in a scenario.

7.2.2 Organizational / Interagency / Cross-border effects

Responding to emergencies with cascading effects is likely to involve a broad range of organizations and groups. In the Oso mudslide for instance more than 900 persons was involved in the search and rescue, and recovery operations. This included local, state, federal personnel and volunteers, contractors, families and neighbors. One conclusion from this is that when relations to the public are discussed during the design of the IET, this discussion should not be limited to issues of passing out information. Instead an inclusive approach could be taken.

The cases presented in this report tell of several organizational issues that hindered response in some way. For example, during the wildfire in Västmanland, responses were run in parallel until the sixth day when the county administrative board finally took over. In the London bombing each branch of emergency service declared major incident separately but did not automatically alert the others. In the Oso Mudslide a Joint Information Center was not established early enough to provide timely and accurate information to responders, emergency management organizations, and affected communities during the most critical phase of the response (rescuing survivors). France has implemented a system which explicitly aims to coordinate a large spectrum of organizations and other actors under one authority, but for other countries the situations is more unclear.

Emergency response may sometimes uncover organizational conflicts and even competitive behavior. If the IET were to be used by one group exclusively then information stemming from the use of that tool could be met with skepticism from other groups of stake-holders. The tool has to be accepted as a valid, shared source of information in the larger collective of responders, and the information that it provides must be trusted by all stake-holders. Cultural heritage, education and experience serve as a framework for sensemaking and culture can also affect how people relate to technology, for example how IT support in general or the underlying logic of a tool such as the IET is valued in a specific national context. These may be important issues to consider when the IET is implemented in a multi-organizational and/or multinational context. If a tool is widely shared it can provide a common ground for decisions

and help fuse the collective of response workers together, in the pursuit of shared goals. Reaching this situation is to some extent made more probable by the fact that the IET is envisioned to be part of training and preparations, because organizations and groups that have had the chance to build trust tend to be more cooperative in collaborative decision-making. It is not inconceivable that a shared tool for information storage, processing and distribution such as the IET could then help lower the cultural or social barriers between groups and organizations. However, every tool is used within a particular context, and its success may be determined by the design and management of related organizational functions.

One issue that should probably be investigated further is the proper level of implementation of the IET. Because engagement of the IET presupposes that cascading effects have been detected, it is important to consider how sufficient knowledge about such effects is built into responding organizations (or other groups). Although the actual users of the IET may be few, related knowledge should perhaps be spread wider.

8 References

Abrahamsson, M., Hassel, H., & Tehler, H. (2010). Towards a systems-oriented framework for analysing and evaluating emergency response.

Armstrong, K., (2014) ”Risk of slide ’unforeseen’? Warnings go back decades”, The Seattle Times – Local News, March 24, 2014.

Asp, V., Bynander, F., Daléus, P., Deschamps-Berger, J., Sandberg, D., & Schyberg, E. (2015). Bara skog som brinner?: Utvärdering av krishanteringen under skogsbranden i Västmanland 2014. FHS 640/2014. Försvarshögskolan/Crismart, Stockholm.

Bergström, J., Dahlström, N., Henriqson, E. & Dekker, S. (2010). Team Coordination in Escalating Situations: An Empirical Study Using Mid-Fidelity Simulation. Journal of Contingencies and Crisis Management, 18(4), 220-230.

Beer, S.(1972). Brain of the Firm. The Penguin Press.

Brandsjö, K. Brandförsvarets historia: från stadsvakter till räddningstjänst. (1986). Svenska Brandförsvarsföreningen.

Bye, A., Hollnagel, E., & Brendeford, T. S. (2000). Principles for Modelling Function Allocation. International Journal of Human-Computer Studies, 52(2), 253–265.

CCS, Civil Contingencies Secretariat, Cabinet office, Emergency Response and Recovery – Non statutory guidance accompanying the Civil Contingencies Act 2004”, (2013). Civil Contingencies Secretariat, London.

Cedergårdh, E. & Wennström. O. (1998). Grunder för ledning, generella principer för ledning av kommunala räddningsinsatser. Statens räddningsverk. Karlstad.

Chen, A., Chen, N., & Li, J. (2012). During-incident process assessment in emergency management: Concept and strategy. Safety Science, 50(1), 90–102.

Comfort, L.K. (2007). Crisis Management in Hindsight: Cognition, Communication, Coordination, and Control. Public Administration Review, 67(s1), 189-197.

Cohen, Marvin S., in Klein, G. A., Orasanu, J., Calderwood, R., & Zsambok, C. E. (Eds.). (1993). Decision-making in action: Models and methods. Norwood, NJ: Ablex Publishing Corporation. 36-)

Crandall, B., Klein, G. A., & Hoffman, R. R. (2006). Working Minds: A Practitioner’s Guide to Cognitive Task Analysis. MIT Press.

Endsley, M. (1995). Toward a theory of Situation Awareness in Dynamic Systems. Human Factors, 37(1), 32-64

Endsley, M.R., Hoffman, R., Kaber, D. & Roth, E. (2007). Cognitive Engineering and Decision-making: An Overview and Future Course. Journal of Cognitive Engineering and Decision-making, 1(1), 1-21.

Fredholm, L & A-L. Göransson (reds.) (2006). Ledning av räddningsinsatser i det komplexa samhället. Räddningsverket.

Greater London Authority, (2006). Report of the 7 July Review Committee, in 3 volumes., London, UK.

Hardy, K. & Comfort, L.K. (2015). Dynamic decision processes in complex, high-risk operations: The Yarnell Hill Fire, June 30, 2013. Safety Science 71, 39-47.

Hollnagel, E., & Woods, D. D. (1983). Cognitive systems engineering: new wine in new bottles. International Journal of Man-Machine Studies, 18, 583–600.

Hollnagel, E. (1993). Human reliability analysis: Context and control. Academic Press.

Hollnagel, E., & Woods, D. (2005). Joint cognitive systems: Foundations of cognitive systems engineering. CRC Press.

Hutchins, E. (1995). Cognition in the Wild. MIT Press.

Hustinx, P., Meeuwis, D. and Hermans, R. (2004).Geneeskundig management bij grootschalige incidenten, Utrecht: De Tijdstroom, 2004 1st edition

Jensen, E. (2009). Sensemaking in military planning: a methodological study of command teams. Cognition, Technology & Work, 11, 103-118.

Journal of Contingencies and Crisis Management, 18(1), 14–25.

Jungert, E., Hallberg, N. & Hunstad, A. (2006). A service-based command and control systems architecture for crisis management. International Journal of Emergency Management, 3(2/3), 131-148.

Kahneman, D. & Klein, G. (2009). Conditions for intuitive expertise: A failure to disagree. American Psychologist, 64(6), 515-526.

Kapucu, N. & Garayev, V. (2011). Collaborative Decision-Making in Emergency and Disaster Management. International Journal of Public Administration, 34, 366–375.

Klein, G. A., Orasanu, J., Calderwood, R., & Zsambok, C. E. (Eds.). (1993). Decision-making in action: Models and methods. Norwood, NJ: Ablex Publishing Corporation.

Klein, G. (1998). Sources of power: How people make decisions. Cambridge, MA: MITPress.

Klein, G. (2000). Analysis of situation awareness from critical incident reports. In M.R. Endsley, & D.J. Garland (Eds.), Situation awareness analysis and measurement (pp.51-71). Mahwah, NJ: Lawrence Erlbaum Associates.)

Klein, G., Ross, K. G., Moon, B., Klein, D. E., Hoffman, R. R. & Hollnagel, E. (2003). Macrocognition. IEEE Intelligent Systems, 81-85.

Klein, G., Moon, B. & Hoffman, R.R. (2006). Making Sense of Sensemaking 1: Alternative perspectives. IEEE Intelligent Systems, 21(4), 70-73.

Klein, G., Phillips, J., Rall, E., & Peluso, D. (2007). A dataframe theory of sensemaking. In Expertise Out of Context: Proceedings of the Sixth International Conference on Naturalistic Decision-making. 113–155.

Klein G.,(2008) Naturalistic Decision-making, Human Factors: The Journal of the Human Factors and Ergonomics Society 50 (3): 456–460.

Klein, G. (2015). A naturalistic decision-making perspective on studying intuitive decision-making. Journal of Applied Research in Memory and Cognition, 4(3), 164-168.

Kokar, M. M., & Endsley, M. R. (2012). Situation awareness and cognitive modeling. IEEE Intelligent Systems, 27(3), 91–96.

Kontogiannis, T. (2012). Modeling patterns of breakdown (or archetypes) of human and organizational processes in accidents using system dynamics. Safety Science, 50(4), 931–944.

Lass, R.N., Regli, W.C., Kaplan, A., Mitkus, M. & Sim, J.J. (2008). Facilitating Communication for First Responders Using Dynamic Distributed Constraint Optimization. IEEE Conference on Technologies for Homeland Security.

Leveson, N. (2004). A new accident model for engineering safer systems. Safety Science, 42(4), 237–270.

Lintern, G. (2010). A Comparison of the Decision Ladder and the Recognition-Primed Decision Model. Journal of Cognitive Engineering and Decision-making, 4(4), 304–327.

Lipshitz, R. (1993). Converging themes in the study of decision-making in realistic settings. In G. A. Klein , J. Orasanu, R. Calderwood, & C. E. Zsambok (Eds.), Decision-making in action: Models and methods (pp. 103-137). Norwood, NJ: Ablex.

Lombardo, K., Boggs, J., Boudreau, J., Chiles, P., Erickson, J., Gerstel, W., Montgomery, D., Shipman, L., Radcliff-Sinclair, R., Strachan, S., Sugimura, D., and Trimm, B., (2014). SR 530 Landslide Commission Final Report.

Lundberg, J. & Asplund, M. (2011). Communication Problems in Emergency response. Proceedings of the 8th International ISCRAM Conference. Lisbon, Portugal.

Masakowski, Y. R. Chapter 7 in Febbraro, A.R., McKee, B. & Riedel, S.L. (2008). RTO-TR-HFM-120 - Multinational Military Operations and Intercultural Factors. NATO Science and Technology Organization

McIlroy, R. C., & Stanton, N. A. (2011). Getting past first base: Going all the way with Cognitive Work Analysis. Applied Ergonomics, 42(2), 358–370.

Militello, L. G., & Hoffman, R. R. (2008). The Forgotten History of Cognitive Task Analysis (pp. 383–387). Human Factors and Ergonomics Society 52nd Annual Meeting, Human Factors and Ergonomics Society, Inc.

Moore, D.T. & Hoffman, R.R. (2011). Data-Frame Theory of Sensemaking as a Best Model for Intelligence. American Intelligence Journal, 29 (2), 145

Naikar, N. (2010). A Comparison of the Decision Ladder and the Recognition-Primed Decision Model. Melbourne, Australia.

Neisser, U. (1976). Cognition and reality. Principles and implication of cognitive psychology. QH Freeman.

Njå O. & Rake E.L., (2009). A discussion of decision-making applied in incident command, Int. J. Emergency Management, Vol. 6, No. 1

Norros, L., Hutton, R., Grommes, P., Colford, N., Liinasuo, M., & Savioja, P. (2009). Analysis of work demands of multi-agency emergency response activity for developing information support systems. In European Conference on Cognitive Ergonomics: Designing beyond the Product - Understanding Activity and User Experience in Ubiquitous Environments (pp. 7:1–7:5). VTT Finland.

Norros, L., Colford, N., Hutton, R., Liinasuo, M. Grommes, P., & Savioja, P. (2009). Analysis of work demands of multi-agency emergency response activity for developing information support systems. European Conference of Cognitive Ergonomics, 92-95. Helsinki, Finland.

Palmqvist, H., Bergström, J., & Henriqson, E. (2012). How to assess team performance in terms of control: a protocol based on cognitive systems engineering. Cognition, Technology & Work, 14(4), 337–353.

Patterson, E. S., & Hoffman, R. R. (2012). Visualization framework of macrocognition functions. Cognition, Technology and Work, 14(3), 221–227.

Quarantelli, E. L. (1997). Ten Criteria for Evaluating the Management of Community Disasters. Disasters, 21(1), 39-56.

Rasmussen, J. (1986). Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering. New York, NY, USA: Elsevier Science Inc.

Rasmussen, J. (1997). Risk management in a dynamic society: A modelling problem. Safety Science, 27(2-3), 183–213.

Sahlin, N-E., Wallin A. & Persson, J. (2009). Decision science: from Ramsey to dual process theories. Synthese, 172 (1), 129-143.

Salmon, P. M., Cornelissen, M., & Trotter, M. J. (2012). Systems-based accident analysis methods: A comparison of Accimap, HFACS, and STAMP. Safety Science, 50(4), 1158–1170.

Salmon, P. M., Goode, N., Archer, F., Spencer, C., McArdle, D., & McClure, R. J. (2014). A systems approach to examining disaster response: Using Accimap to describe the factors influencing bushfire response. Safety Science, 70, 114–122.

Sanderson, P., Naikar, N., Lintern, G., & Goss, S. (1999). Use of cognitive work analysis across the system life cycle: From requirements to decommissioning. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 43(3), 318–322.

Schraagen, J.M., Huis in „t Veld, M. & de Koning, L. (2010). Information Sharing During Crisis Management in Hierarchical vs. Network Teams. Journal of Contingencies and Crisis Management, 18(2), 117-127.

Simon, H. A. (1955). A behavioral model of rational choice. The Quarterly Journal of Economics, 69 (1), 99-118.

Stanton, N. A., & Bessell, K. (2014). How a submarine returns to periscope depth: Analysing complex socio-technical systems using Cognitive Work Analysis. Applied Ergonomics, 45(1), 110–125.

Svedung, I., & Rasmussen, J. (2000). Proactive Risk Management in a Dynamic Society. Karlstad: Swedish Rescue Services. Karlstad: Risk & Environmental Department, Swedish Rescue Services Agency.

Svedung, I., & Rasmussen, J. (2002). Graphic representation of accident scenarios: Mapping system structure and the causation of accidents. Safety Science, 40(5), 397–417.

Svensson, S. (Ed.) Cedergårdh, E. Mårtensson, O. & Winnberg, T. (2009) Tactics, Command, Leadership. Swedish Civil Contingencies Agency.

Svensson, S., (2015), First Responder Activities: the Swedish fire service, CascEff Report 001.

Tversky, A., & Kahneman, D. (1974). Judgment under unoertainty: Heuristics and biases. Science, 185, 1124-1131.

Uhr, C., Frykmer, T., Koelega, S., Cedergårdh, E., Ekman, O., Fredholm, L., & Landgren, J. (2015). Att åstadkomma inriktning och samordning-7 analyser utifrån hanteringen av skogsbranden i Västmanland 2014.

Van Santen, W., Jonker, C. & Wijngaards, N. (2009). Crisis decision-making through a shared integrative negotiation mental model. International Journal of Emergency Management, 6(3/4), 342-355.

Weick, K. (1995). Sensemaking in Organisations. London: Sage.

Wilke A. and Mata R. (2012) Cognitive Bias. In: V.S. Ramachandran (ed.) The Encyclopedia of Human Behavior, vol. 1, pp. 531-535. Academic Press.

Wilson, J. R. (2014). Fundamentals of systems ergonomics/human factors. Applied Ergonomics, 45(1), 5–13.

Winters, C.,(2014) ”Finding cause of Oso mudslide will take time and science”, HeraldNet.com – Local News, Sunday, May 11, 2014, http://www.heraldnet.com/article/20140511/NEWS01/140519850

Woods, D. D., & Roth, E. M. (1988). Cognitive engineering: Human problem solving with tools. Human Factors, 30(4), 415–430.

Wucholt, F., Yildirim-krannig, Y., Mähler, M., Krüger, U., & Beckstein, C. (2011). Cultural Analysis and Formal Standardised Language — a Mass Casualty Incident Perspective. In the 8th International ISCRAM Conference. Lisbon, Portugal.

Yao, X., Turoff, M. & Chumer, M.J. (2010). Designing a group support system to review and practice emergency plans in virtual teams. International Journal of Emergency Management, 7(2), 137-150.

Yates, J.F. (2003) Decision Management. How to Assure Better Decisions in Your Company, San Francisco, CA: Jossey-Bass.

Zachary, W., Hoffman, R., Crandall, B., Miller, T., & Nemeth, C. (2012). “ Rapidized ” Cognitive Task Analysis. IEEE Intelligent Systems, 27(2), 61–66.

Non-academic references

Clément Judek at University of Lorraine, information provided by email, 6 of April, 2016.

FPS Interior (2013), Brochure Noodplanning and Crisis management, Brussels, 28 p., from http://centredecrise.be/nl/publication/noodplanning-en-crisisbeheer-belgie-0

Hans Kristian Madsen at the Directorate for emergency planning, DSB, information provided by email, 2015.

http://www.msb.se

http://www.jesip.org.uk

Joint Doctrine: The Interoperability framework, JESIP, 2013.

Justitiedepartementet. (2015). Rapport från Skogsbrandsutredningen.

Länstyrelsen i Västmanlands län. (2014). Skogsbranden i Västmanland 2014: En dokumentation utgiven av Länstyrelsen i Västmanalands län.

MSB. (2015). Observatörsrapport - Skogsbranden i Västmanland 2014: Myndigheten för samhällsskydd och beredskap.

SKL. Öppna jämförelser, Trygghet och säkerhet 2014. Sveriges Kommuner och Landsting. 2014

Wikipedia Last changed 16 September 2014 <nl.wikipedia.org/wiki/Geco%C3%B6rdineerde_Regionale_Incidentbestrijdings_Procedure>

Van Campen, Steven, (2010). Dynamic Gubbar System - Support tool for exercises in disaster management logistics, Delft: Delft University of Technology.

Regulations:

Act (2006: 544) of municipalities and county councils measures before and during extraordinary events in peacetime and heightened preparedness (Sweden)

Arbetsmiljöverkets föreskrifter om Rök- och kemdykning. AFS 2007:7. Stockholm. 2007. (Sweden)

Arbetsmiljöansvar och straffansvar. Arbetsmiljöverket. 2012. (Sweden)

Civil protection act (2003:778) (Sweden)

Civil protection regulation (2003:789) (Sweden)

EMDM Academy Proposal to establish an international centre for education and research in disaster medicine, www.dismedmaster.com, 2007 (Netherlands)

Government bill 2002/03:119 Reformed civil protection laws (Sweden)

Local government act (in Swedish: Kommunallag). 1991:900. (Sweden)

Law of 15 May 2007 on Civil Security, O.G. 31.07.2007 (Belgium)

Royal Decree of 14 October 2013 on the minimal content of the risk analysis cf. art. 5 Law Civil Security 15 May 2007, O.G. 30.10.2013 (Belgium)

Royal Decree of 10 November 2012 establishing minimal terms and conditions for fast adequate response and means (Belgium)

Royal Decree of 16 February 2006 on Emergency and Intervention planning, O.G. 15.03.2006 (Belgium)

Appendix 1 Modelling large-scale evacuation of music festivals due to cascading incidents

This appendix explores the use of multi-agent continuous evacuation models for representing cascading large-scale evacuation scenarios of music festivals, scenarios selected for specific studies within CascEff. Note that the appendix has a separate reference list at the end of the appendix.

A1.1 Introduction

Incident commanders need to make decisions to safeguard lives when assessing cascading effects. When deciding on evacuation of large number of people it is important to establish a strategy that will minimize the evacuation time and reduce casualties.

The loss of life during major incidents at several European music festivals over the past decade illustrates the importance of developing crowd management strategies that can be deployed in the case of emergencies (Berlonghi, 1995; Fruin, 1993; Helbing &Mukerji, 2012; Still, 2013). The causes of these incidents may be very difficult to predict. For example, in 2000 nine people died at the Roskilde festival in Denmark when the crowd fell in front of the stage (Lee & Hughes, 2005). Overcrowding would also lead to 21 fatalities at the 2010 Love Parade in Duisburg, as revellers crammed into a tunnel at the entrance of the festival site (Krausz & Bauckhage, 2012; Pretorius, Gwynne, & Galea, 2015). Unexpected extreme weather conditions may also threaten the safety of festival goers, as was seen during the 2011 Pukkelpop festival disaster when a tent collapse killed five and injured more than 300 people.

Today evacuation safety measures for music festivals are based on guidelines (rules of the thumb) discussing variables such as the width of available exit space depending on the number of people, maximum number of people per m^2, etc. (Health and Safety Executive, 1999). Evacuation exercises to test festival evacuation plans are rarely done. Evacuation modelling to test festival evacuation plans and procedures are an easier way to evaluate and improve the safety of music festivals. However this technique is seldom used as organisers and local authorities rely on the current practice of evacuation guidelines.

Music festivals present a set of challenges from the perspective of crowd and evacuation safety. For instance, very high people densities can be reached in proximity of the stages, thus creating potential issues associated with crushing and trampling (Harding, Amos, & Gwynne, 2010; Smith & Lim, 1995). Attendees are often unfamiliar with the evacuation routes, thus potentially increasing the time needed for way-finding during such incidents(Arthur & Passini, 1992). Pre-evacuation behaviour itself (which Proulx (2002) defines as the time needed to start the purposive movement towards a safe place) may be affected by several variables such as the impact of social media (Cassa, Chunara, Mandl, & Brownstein, 2013; Potts, 2014) or levels of alcohol consumption (Chapman, Carmichael, & Goode, 1982; Moore, Flajšlik, Rosin, & Marshall, 2008).

Several questions can be raised about the adequacy of the emergency procedures adopted in large music festivals. What type of evacuation scenarios should be considered when designing evacuation routes to account for possible cascading effects? What emergency procedures should be employed to improve evacuation efficiency? There are no straightforward answers to these questions as they often depend on the specific characteristics of the festival under consideration. Crowd management at festivals is further complicated by the fact that many

aspects concerning the behaviours of people during emergency scenarios remain under-researched (Kuligowski, 2011).

The complexity of large-scale evacuation at music festivals increases during incidents involving cascading effects. Cascading effects are the impacts of an initiating event where system dependencies lead to impact propagating to other systems, the combined impacts of the propagated events are of greater consequences than the root impacts and multiple stakeholders and responders are involved. In a crisis situation, cascading evacuation scenarios are those in which there is a gradual increase in the area that needs to be evacuated (not necessarily adjacent) due to the cascading effects from the primary incident. Escalating scenarios are scenarios in which this increase is not necessarily dependent on the primary incident. Cascading scenarios involve an initial threat and several possible chains of events, each with the potential to greatly increase the complexity of crisis management and decision-making. The study of their implications on evacuation strategies is therefore of key importance for safety designers and crowd managers in their efforts to avoid future disasters.

In this context, evacuation modelling could be a useful tool to investigate different cascading large-scale evacuation scenarios and support decision-making during these incidents(Alvear, Abreu, Cuesta, & Alonso, 2013). For instance, a user that is aware of model limitations and uncertainties could effectively use evacuation models to analyse and compare different evacuation strategies (Ronchi, Kuligowski, Nilsson, Peacock, & Reneke, 2014; Ronchi & Nilsson, 2014). Evacuation models can be used to obtaining qualitative and quantitative information on evacuation times and space usage in different evacuation scenarios (S. Gwynne, Galea, Owen, Lawrence, & Filippidis, 1999). The behaviour of festival goers and members of staff can also be explored using these models (Magnolo, Manenti, Manzoni, & Sartori, 2009; Wagner & Agrawal, 2014).

A model case study was developed in order to explore the current capabilities and limitations of evacuation models for the simulation of music festival evacuation scenarios. A fictional music festival was created, the characteristics of which were informed by a review of several real ones by the researchers. The music festival area is able to host up to 65,000 people and includes eleven stages. Three evacuation scenarios were devised, in which different threats and available evacuation routes were assumed. These scenarios were used to explore the capabilities of evacuation models to simulate complex cascading evacuation scenarios involving the activities of large numbers of people.

A review of the characteristics that evacuation models need to include in order to simulate this type of scenarios was performed. This included the representation of large populations and high densities, as well as related issues such as the pressure exerted on safety barriers. Following this review, a set of simulations was performed using an agent-based continuous model - Pathfinder (Thunderhead Engineering, 2014). A continuous model represents the space using a system of coordinates (Ronchi & Nilsson, 2015).

The objectives of the study were as follows:

1) To review the capabilities, assumptions and limitations of evacuation models to simulate large-scale evacuation scenarios at music festivals generated by initiators causing cascading effects.
2) To investigate the impact of human behaviour by comparing a set of possible evacuation scenarios and strategies by using evacuation modelling tools.

3) To provide suggestions and recommendations for improving the evacuation efficiency of large-scale evacuation scenarios at music festivals generated by initiators causing cascading effects.
4) To identify possible future research areas on this topic.

A1.2 Method

The method employed in this study was the application of evacuation modelling techniques. Evacuation modelling has been employed in several applications in complex environments, such as fire safety in high-rise buildings (Ronchi & Nilsson, 2014) and aircrafts (Bukowski, Peacock, & Jones, 1998), risk analysis of road tunnels (Ronchi, 2013), crowd management in ships (Roh & Ha, 2013), etc. Recent research studies have also investigated the applicability of crowd models for the study of people movement at large festivals (Magnolo et al., 2009; Pretorius et al., 2015; Wagner & Agrawal, 2014).The initial phase of the study is therefore the selection of an appropriate evacuation model to simulate large-scale evacuation scenarios at a music festival.

Three different levels are available to perform evacuation simulations (Lord, Meacham, Moore, Fahy, & Proulx, 2005), namely open, blind and specified calculations. These calculations vary the level of information about the scenarios to be simulated, i.e. information necessary for the calibration of the model input. A blind calculation is performed when only basic information is available on the scenario to be simulated, a specified calculation includes a detailed description of the model input, and open calculations are the case in which the model user has complete information about the scenario (including benchmark data or model runs). Specified calculations were performed in respect of the objectives of the study. Hence a set of hypothetical scenario characteristics and agent behaviours were assumed and implemented within the model. These type of calculations are deemed suitable for the testing of the underlying algorithms and capabilities of the models rather than the impact of the user on results (Lord et al., 2005).

When possible, the input of the evacuation model was calibrated using experimental data rather than the default settings of each model. This had the effect of making the evacuation scenarios as realistic as possible, while limiting the user effect (Ronchi, 2013), i.e., results affected by the choices of the modellers during the process of input calibration. The user effect may in fact cause that the predictive capabilities of the models are dependent on the modeller's expertise and assumptions, rather than the model sub-algorithms. This is reflected in the possible impact of evacuation model default settings, which has been found in many contexts as a determinant factor of evacuation model results (S. M. V. Gwynne, Kuligowski, Spearpoint, & Ronchi, 2013; Ronchi, Gwynne, & Purser, 2011).

A1.3 Limitations

This study focused on the application of evacuation models for the study of cascading large-scale evacuation scenarios at music festivals. Clearly not all cascading evacuation scenarios could be explored in the model case study. Nevertheless, the model case study was designed in order to give a vast range of applicability to the findings of this study. For this reason, the characteristics of the model case study were selected on the basis of their representativeness of current music festivals, after consultations with event and safety managers. The researchers still had to impose certain features on the case study that had the potential to significantly affect the results (e.g., area configuration, population type and characteristics, available evacuation routes, management and emergency notification procedures, etc.). In addition, some of the assumptions were based on the literature, which in some cases may not have

provided data to predict some behavioural elements (e.g. delay times, adopted walking speeds and way-finding of the population, etc.). For this reason, the model case study should be considered as an ideal case; it was an explorative study of the predictive capabilities of evacuation models in certain conditions rather than a complete assessment of the behaviour of people in such type of scenarios. It should also be noted that threats other than those considered in these scenarios might act as triggers for evacuation.

The number of scenarios was restricted to a set of severe (but plausible) significant configurations in the current crowd management practice, although it was also possible to simulate additional evacuation scenarios/strategies.

The choice of the evacuation model employed in this study was made after analysis of the characteristics of evacuation models as stated by model developers, e.g. the model inventory available at www.evacmod.net (Ronchi & Kinsey, 2011) or presented in scientific reviews (S. Gwynne et al., 1999; Erica D. Kuligowski, Peacock, & Hoskins, 2010). The capabilities of evacuation models are constantly evolving (Ronchi & Kinsey, 2011) and the subsequent suitability of additional models for projects can vary rapidly. In addition, many evacuation models present sufficient flexibility to be employed for cascading large-scale evacuation scenarios even if they are not able to explicitly represent some of the variables. For this reason, the selected model should not be considered as the only suitable model for simulating these type of scenarios, i.e., this study could have been performed also with different models. Inexpert model users may not be aware of the impact of the intrinsic assumptions of the models, thus results should be evaluated carefully (Ronchi, Kuligowski, et al., 2014).

A1.4 Model Case study

The model case study was an outdoor dance festival in an area restricted by fences due to its close proximity to a residential area, river and main road transport infrastructure (highway and secondary roads). The area was used for music performances at different stages (eleven) as well as a small temporary stadium could be erected on the site. The maximum number of attendees was 65,000 people, most of whom were likely to be aged between 16 and 35 years old.

Three evacuation scenarios were taken into consideration, in which different threats and available evacuation routes are assumed. Three evacuation scenarios were developed in order to explore the predictive capabilities of evacuation models during such incidents:

1. A preventive evacuation of a section of the festival area containing approximately 15,000 people due to a fire breaking out on a ship close to the festival site;
2. While the preventive evacuation is ongoing, an escalating scenario involving the total evacuation of the entire festival area (65,000 people) due to a bomb threat;
3. While the preventive evacuation is ongoing, a cascading scenario involving the total evacuation of the entire festival area (65,000 people) due to the threat of an explosion caused by the overheating of the ship engine.

<u>Scenario 1</u>

In Scenario 1, the hypothetical initiator of the evacuation was a ship transporting Ammonium nitrate (NH_4 NO_3), which was navigating the river close to the festival site. The captain was distracted by white fumes coming from the vessel's hold and made a navigation error that lead to the ship colliding with a buoy near the quay next to the music festival. The captain reported this to marine traffic control after the cargo appears to start accidental decomposition. Festival

attendees saw the white smoke coming towards them. Fireworks in the production village of the festival detonated prematurely. The fire brigade responded to these incidents by ordering the preventive evacuation of the north/north-east section of the festival area, which contained approximately 15,000 people.

Escalating Scenario 2

In escalating Scenario 2, while the preventive evacuation of a section of the area was taking place (Scenario 1), a bomb threat video was issued on social media by a self-declared jihadi terrorist organization. They condemn the festival as young people are consuming alcohol, have sexual intercourse and listen to 'satanic' music. They demand that the members of the jihadi organization on trial in the nearby court house are released; otherwise a bomb at the festival area will explode. The city's social media monitoring team picked up the message, and due to the fireworks explosion earlier and an ongoing trial in the courthouse about prisoners of the terrorist organization, the mayor took the decision to evacuate the whole festival area (65,000 people).

Cascading scenario 3

In the third scenario, while the preventive evacuation of a section of the area was taking place (Scenario 1), the ship's engine has overheated and set on fire. The fire caused oil to be spilt in the hold, increasing the risk of the fire spreading throughout the ship. The cooling of the cargo was not successful (temperature has reached 210° C) and the self-sustained decomposition process could not be stopped. There was an immediate danger of detonation of the Ammonium Nitrate. The risk of an explosion led the fire brigade with no choice but to evacuate the entire festival area (65,000 people) given a lethal threat zone of 2 km surrounding the ship.

A1.4.1 Festival area configuration

A schematic two-dimensional representation of the festival area and stage location is presented in Figure A1.1. The area in grey in Figure A1.1 represents the area where people are initially located. The lines in green represent the exit paths towards the northern part of the festival area. The area in yellow Figure A1.1 is not available for evacuation. The approximate location of the stages is indicated in Figure A1.1. Exit widths are presented in table A1.1.

Table A1.1 Exit widths (both internal and external) of the festival area.

Exit number	Width (m)	Exit number	Width (m)
Fin_Ex1	9	Ex3E	15.5
Fin_Ex2	45	Fin_Ex4	8.5
Fin_Ex3A	7.5	Ex4	7
Fin_Ex3B	7.5	Fin_Ex5	7.5
Ex3A	7	Ex5	7
Ex3B	7	Fin_Ex6	7.5
Ex3C	7	Ex6	7
Ex3D	3.3		

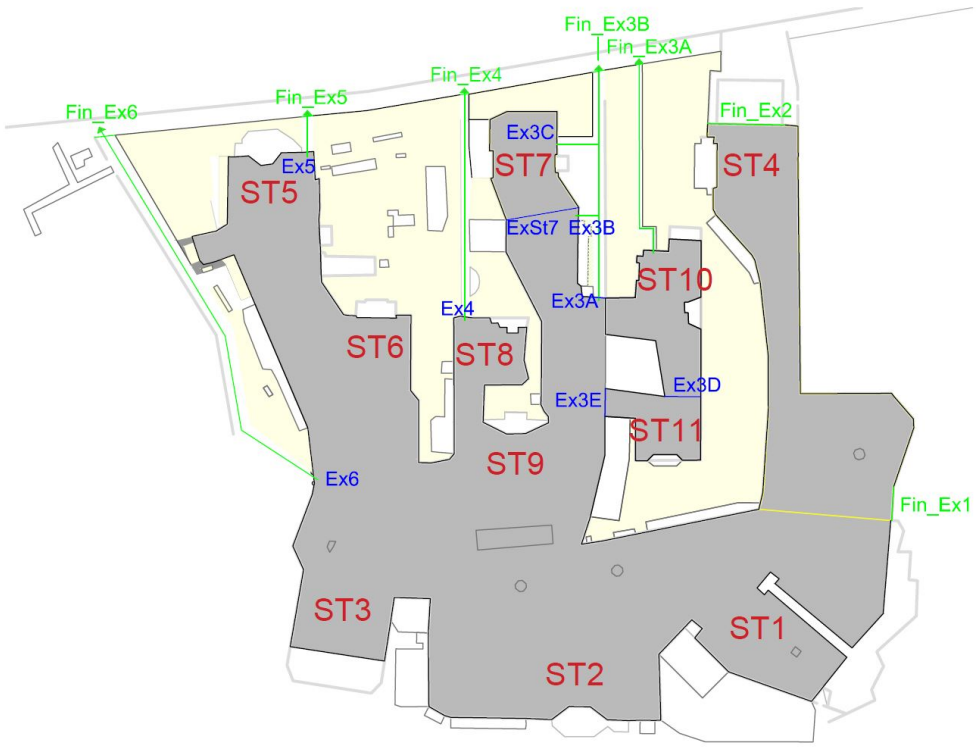

Figure A1.1 Schematic two-dimensional representation of the festival area. Legend: STX=Stage number, ExX=Exit of stage number x, Fin_ExX=Final exit number x.

In case of evacuation, fences close to the exits used for the delimitation of the festival are usually open. External exits have a width in the range of 7.5-9 m, except the main entrance of the festival area (Fin_Ex2 has a width of 45 m).The location of the exits is presented in Figure A1.1. It should be noted that the area outside the boundaries of the festival area includes a large available space to accommodate the entire festival population in case of emergency from which people leave using public transportation (the festival area is assumed to be located in the outskirts of a city).

A1.4.1.1 Initial people location

The initial people location and density is assumed given the maximum number of people that the festival can accommodate (65,000 people). People density close to the stages is assumed to be higher than in other areas of the festival site. Based on discussions with different festival organizers, the starting average people density is assumed equal to 2 people/m^2 at the outdoor stages and 3 people/m^{2}for the indoor stages. This could be due to high density in close proximity to the stages (even higher than 4 people/m^2) and a lower density in areas situated further away from them (approximately 1 people/m^2). The population placing is then adjusted in order to consider 10 % of the population that is not on the stages and that the upper limit of the population allowed in the festival area is 65000 people. Given these assumptions, the number of people in the proximity of each stage is presented in Table A1.2.

Table A1.2 Assumed number of people initially located in part of the festival area.

Stage	Outdoor (2pp/m^2) Indoor (3 pp/m^2)	People number
1	Out	16455
2	Out	10531
3	In	3949
4	Out	1028
5	Out	5759
6	In	3159
7	In	5332
8	In	1975
9	Out	6952
10	Out	2962
11	In	987
ST		59089
NoST		5,911
Tot		65000

Legend:*ST= Tot people close to the stages, **NoST= people on festival area (not on stages)

A1.4.1.2 Emergency communication

A set of assumptions in relation to the emergency communication strategies was made in order to calibrate the model for the behaviour of attendees during an emergency. It was assumed that all of them would have received a festival map (on paper and courtesy of the festival app) with information on stages and emergency exits and that this information has been read and correctly understood. Eight to nine screens would be erected in prominent areas within the festival site to convey standard emergency messages to attendees. Every stage would have a stage manager equipped with standard messages to be broadcast over the PA system in case of emergencies. As a back-up each stage manager would also have a megaphone to communicate these emergency messages. All exits had layer-towers of 6-8 meters in height (depending on the visibility) with the exit symbol and the number of the exit. Those assumptions were deemed to have an impact on the assumed pre-evacuation and way-finding behaviour of the attendees, i.e., attendees were assumed to be aware of the available exits.

A1.4.2 Evacuation strategies

Scenario 1 involved the partial preventive evacuation of a section of a festival area due to a fire on a nearby ship. Assuming the fire occurring on a vessel on the river close to the north/north-east part of the festival area, a total of 15,309 attendees would need to be evacuated from the areas in close proximity to stages 4, 7, 10, and 11. In Figure A1.2, Fin_Ex1 is the only available exit for the evacuation (the exits on the north/north-east part, i.e., Fin_Ex2, Fin_Ex3B and

Fin_Ex3A are assumed to be not available) and attendees are also relocated to the central part of the festival area (See Figure A1.2). This is possible due to the fact the central part of the festival area includes a space able to accommodate the attendees evacuated by the other stages.

In order to provide insight into the impact of the blocked exits upon the evacuation process, a benchmark case was also considered (Scenario 1a) in which the preventive evacuation scenario was simulated again but with all exits considered available (i.e. including the exits in the north/north-east part of the festival). In addition a scenario 1b is also considered where the exits on the north/north-east part, i.e., Fin_Ex2, Fin_Ex3B and Fin_Ex3A are assumed to be unavailable (as in Scenario 1), but an additional provisional 9 m wide exit is created in the proximity of Fin_Ex1 by removing fences. This exit is added to test the impact of the increase in egress capacity and reduced walking distance.

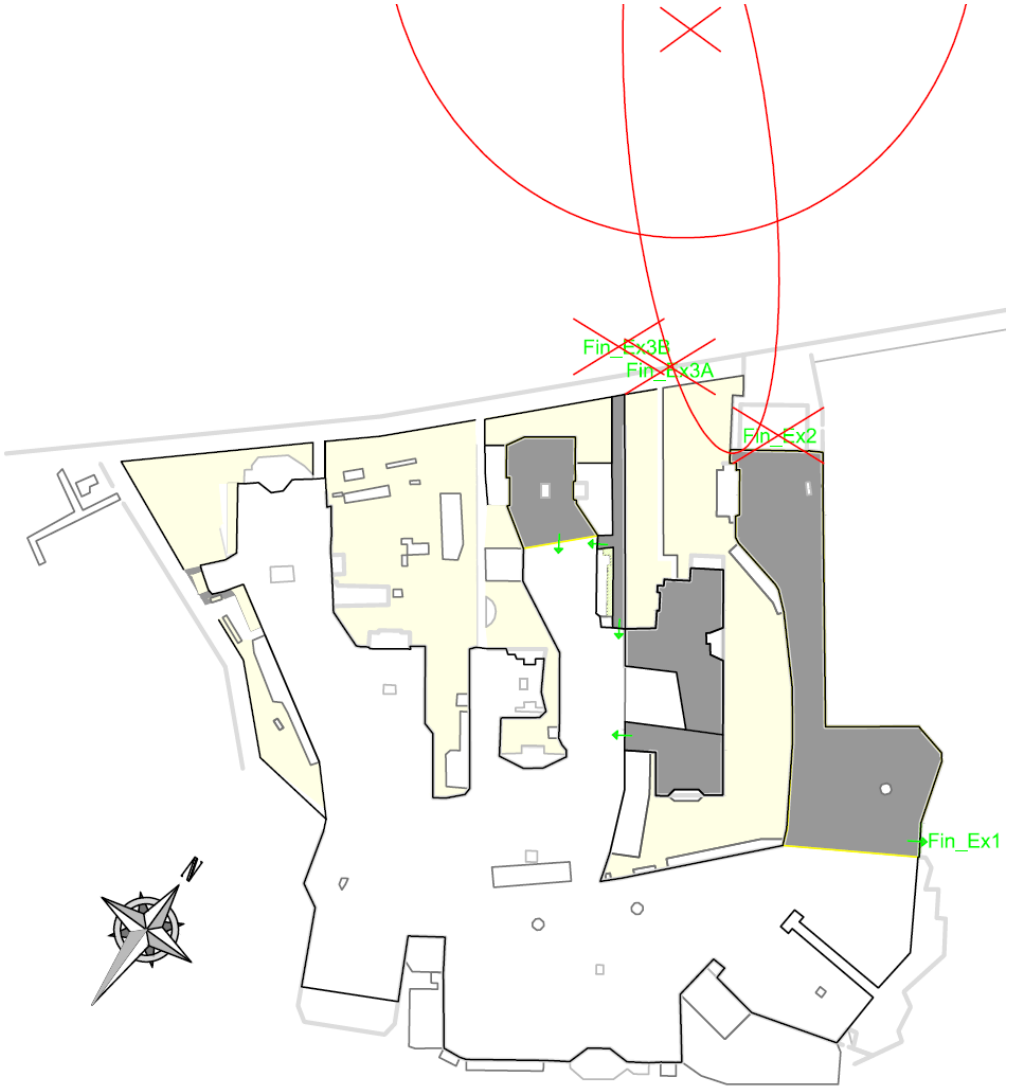

Figure A1.2 **Schematic two-dimensional representation of Scenario 1. The green arrows indicate the relocation strategies. The grey area represents the section of the festival area that is evacuated in scenario 1 (occupied by approximately 15,000 people). The northern red cross indicates the location of the ship and the red lines represent the hypothetical development of the threat.**

The two cascading scenarios (Scenarios 2 and 3) involved the total evacuation of the entire festival area, containing an estimated 65,000 people. In this case, all exits were available except Fin_Ex2, Fin_Ex3B and Fin_Ex3A (see Figure A1.2). Attendees were expected to move to one of the available exits in order to leave the festival area (see all exits available in Figure A1.1).Table A1.3 presents a summary of the available exits and number of people in each scenario.

Table A1.3 Summary of number of people and available exits in the evacuation scenarios under consideration.

Scenario	Available exits	People (#)
1	Fin_Ex1, centre of the festival area	15309
1a	All	15309
1b	Fin_Ex1, centre of the festival area, provisional additional exit	15309
2	All except Fin_Ex2, Fin_Ex3B and Fin_Ex3A	65000
3	All except Fin_Ex2, Fin_Ex3B and Fin_Ex3A	65000

A1.4.3 Crushing issues

Large-scale evacuation in festival areas can be associated with issues regarding crowd crushing and crushing on barriers, in particular in presence of high densities. Examples of deaths due to asphyxia caused by crowd crushing in high-densities are reported as far back as 1837, when Ollivier described people being trampled to death during crowd disturbances in Paris (Richards & Wallis, 2005). In the present case, the festival evacuation represents a typical example of a crowded area in which densities are particularly high.

Standing areas and the use of crush barriers within football stadia have largely disappeared over the last two decades due to the loss of life seen during the Heysel (Young, 1986) and Hillsborough disasters (Elliott & Smith, 1993; Smith, 1994). However, they are still frequently used in music festivals to reduce the built up pressure on the crowds and to avoid a repeat of the fatalities seen during such incidents.

In the present case study, a small temporary stadium is present in the festival area. The stadium is organised in fifteen platforms with a width of 1.38m (*w* in Figure 3) and the step height (*h* in Figure A1.3) between them is equal to 0.17m. This has been inserted to evaluate possible crushing issues with safety barriers, while crowd crushing has not been investigated in the present work.

A1.4.4 The selection of the evacuation model

Different categorizations exist on models for the simulation of pedestrian dynamics in case of evacuation. Models can be divided into macroscopic and microscopic models in relation to the level at which crowd dynamics are simulated, either an aggregate level (macroscopic) or individual level (microscopic, in which each individual agent has its own properties). The approach in use affects the computational time needed for the simulation (microscopic models demand more computational resources) and the level of sophistication in the representation of crowd dynamics and behaviour.

Models can also be categorized in relation to their space representation (Erica D. Kuligowski et al., 2010; Ronchi & Nilsson, 2015), or the method used for the simulation of people movement, e.g., force-based (Helbing & Molnár, 1995), cellular automata (Pelechano & Malkawi, 2008) or multi-agent based systems (Pan, 2009). According to the first classification, models can be divided into coarse network, fine network, continuous and hybrid models. Coarse network models use nodes and arcs to represent the space. Fine network models adopt a discretization of the space in a grid of cells. Continuous models use a system of coordinates to represent the

space. Hybrid models include the possibility to adopt two or more of these space representations (Chooramun, 2011).

Existing research on crowd modelling in case of large-scale evacuation is mostly based on modelling assumptions aimed at low computational cost (given the large number of people involved), e.g., macroscopic simulations (Bellomo & Dogbé, 2008; Piccoli & Tosin, 2011) or cellular automata (Bandini, Rubagotti, Vizzari, & Shimura, 2011).

The present study aims at simulating large-scale evacuation scenarios with a higher level of sophistication, i.e., adopting a multi-agent-based model with a continuous modelling approach. One of the main advantages of continuous models is their capability to simulate high density conditions in a more realistic and accurate way given the continuous representation of the space which is contrast with the cases in which a discretization of the space would affect the maximum achievable densities. For this reason, these types of models provide a better representation of the crowd for the simulation of scenarios in which high densities can occur. In addition, given the need to simulate the impact of the decision-making of each individual festival attendee in case of evacuation, an agent-based approach is recommended. In fact, a multi-agent-based approach simulates individually autonomous agents which can act in accordance to a set of behavioural rules (defined by the model developers or the users).The last issue to consider while selecting a suitable model is the need to simulate a large population (up to 65,000).

Reviewing the characteristics of evacuation models, the model Pathfinder (Thunderhead Engineering, 2014)was selected as one of the model fulfilling the criteria listed above, i.e. it was a continuous model in which people movement was represented with an agent-based modelling approach and it could be used to simulate a large number of people.

A1.4.5 Model application

The model Pathfinder was used to simulate the three evacuation scenarios at the music festival. The process of model input calibration and analysis of results is presented below.

A1.4.5.1 Model input calibration

This section presents the methods/assumptions employed to calibrate the input of the evacuation model such as the assumed agent walking speeds, pre-evacuation delays, behavioural modelling, evacuation route usage, etc. Since one of the main scopes of the study is to represent a realistic evacuation scenario, the calibration of the model input has been based (when possible) on available real data.

Agent characteristics

The physical abilities of people in the festival area were represented through their approximate unimpeded walking speed distributions (see Table A1.4). Two categories were used, namely “standard occupant” and people with locomotion impairments(K. E. Boyce, Shields, & Silcock, 1999). This second category was used in order to represent people with both permanent and temporary locomotion impairment (for instance people who had consumed alcohol at the music festival might be considered to have some form of temporary impairment). The unimpeded walking speeds were represented with truncated normal distributions in order to account for the variability of people abilities. Those values are derived from previous experimental research (K. E. Boyce et al., 1999; K. Boyce, Shields, & Silcock, 1999; Korhonen & Hostikka, 2009). In total, 30 percent of the attendees of the festival were assumed to have locomotion impairments.

***Table A1.4 Unimpeded walking speeds for standard occupants and people with locomotion impairments based on* (K. E. Boyce et al., 1999; K. Boyce et al., 1999; Korhonen & Hostikka, 2009).**

"Standard" occupant (m/s)			**Occupants with locomotion impairments (m/s)**		
Mean	Standard deviation	Range	Mean	Standard deviation	Range
1.29	1.00	0.29-2.29	0.8	0.37	0.1-1.68

The concept that a crowd usually panic in case of evacuation was abandoned by the scientific community since insights from actual events showed that this rarely occurs (Fahy, Proulx, & Aiman, 2012). The evacuation process was therefore represented within evacuation models using a time-line approach (Purser & Bensilum, 2001) based on the fundamental assumption that a crowd behave rationally. The time needed for evacuation was divided into different components. These included the pre-warning time, the time before the emergency was raised, and the time for the attendees to take a decision to evacuate (so-called pre-evacuation time (Proulx, 2002)), which were represented using a single component of time called *delay time*. The assumed delay time would have a critical impact on the total evacuation time since it referred to a set of activities that would take place in case of emergency (e.g. the discovery of the threat, time to start the warning, decision-making by staff and attendees, etc.).

Based on the communication strategy in the present case study and the possible influence of social media, the assumed delay times are provided in Table 4. The studies from (Purser & Bensilum, 2001) also demonstrate that an appropriate representation of delay times can be made through the use of log-normal distributions. These assumptions are based on previous real emergencies (Helbing & Mukerji, 2012; Erica D. Kuligowski & Mileti, 2009), existing literature on the impact of social media during emergencies (Branicki & Agyei, 2015; Cassa et al., 2013) and private communication with festival organizers and first responders. In fact, other large-scale emergencies (e.g. the terroristic attack at the World Trade Center in 2001) have shown that delay time distributions in those types of large emergencies can have a maximum time in the order of 10-15 min (600-900 s) (Kuligowski, Peacock, & Averill, 2013)and that the news of such type of large scale emergencies can appear within 3 min (e.g. in the Boston Marathon bomb (Cassa et al., 2013).

In Scenario 1 (and sub-scenarios 1a and 1b), only apart of the festival population (15,309 people) was evacuated (see Figure A1.2). Since this was a preventive evacuation scenario managed by the staff of the festival, the delay times were assumed to be within 600 s (10 min) (see Table A1.5 for the exact time distribution employed). In the cascading scenarios 2 and 3, while the preventive evacuation was ongoing, a total evacuation was also triggered in the remaining part of the festival area for two different causes (bomb threat in scenario 2 or the overheating of the ship engine in scenario 3). Given the direct visibility of the smoke coming from the ship in scenario 3, it was assumed that the delay time would be shorter (maximum of 750 s, i.e., 12 min and 30 s, see Table A1.5) than that of the bomb threat scenario, where the threat was not directly visible. In scenario 2, the delay time was assumed to not exceed 900 s (15 min) (see Table A1.5).

Table A1.5.Assumed delay time distributions.

Scenario	**Avg (s[min])**	**St Dev (s[min])**	**Min (s[min])**	**Max (s[min])**

1-1a-1b (preventive)	360[6]	120[2]	180[3]	600[10]
2 (bomb threat)	480[8]	150[2.5]	240[4]	900[15]
3 (engine overheating)	420[7]	135[2.25]	210[3.5]	750[12.5]

It should be noted that the assumed delay time distributions are therefore the main variables which is assumed to be affected by the different type of initiators in Scenarios 2 and 3. This is associated with the different levels of risk perceptions assumed in the different scenarios and the way this might affect people response in case of emergency.

People movement

People movement was represented within Pathfinder adopting the embedded multi-agent-based approach in which each agent has its own individual properties. The evacuating population is simulated using a set of equations (which can be found in (S. M. V. Gwynne & Rosenbaum, 2008)) in which the population moves from an evacuation component to another (e.g. from an open corridor to a door/gate, etc.). Route choice is simulated using the default algorithm of the model in which a *locally quickest*[1] path planning approach is used, i.e. routes are ranked hierarchically using local information about people location and queuing times at exits. To produce paths, the model uses a modified version of the A* search algorithm (Hart, Nilsson, & Raphael, 1968) based on string pulling (Johnson, 2006) and triangulated navigation meshes.

Modelling crushing on barriers

Safety barriers would not provide the same level of comfort to all people because this depends on the position of the person with respect to the barrier. In this way, people in front of the barrier would experience the biggest level of comfort in contrast to those just behind it that may receive a greater level of pressure. When designing crush barriers, two main issues need to be avoided (Smith, 1994). On one hand, the pressure built up must not be such to create breathing problems or any kind of injures to those behind it. On the other hand, it must also be proven that the force produced by the crowd is not enough to break the barrier creating crushing issues where people will fall over each other putting their lives in risk.

In this work, the *leaning crowd model* was adopted. This model was first developed for the investigation into the Hillsborough disaster in 1989(Smith, 1994). Since then, it has also been used to analyse the disaster of the Miyun Rainbow bridge during the Lantern Festival of China in 2004 (Zhen, Mao, & Yuan, 2008). The model was developed through the observation of the body position of people standing on a platform and their response to different loads. Using video footage of the Hillsborough football disaster, as well as some laboratory experiments, the leaning position of people was determined as per the diagram in Figure A1.3 (Smith, 1994).

[1] The term *locally quickest* is defined and employed in the technical reference of the Pathfinder model.

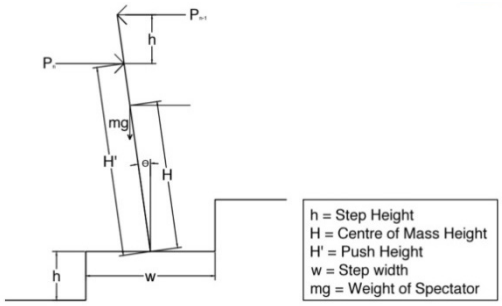

Figure A1.3 Schematic representation of the variables assumed in the leaning crowd model by Smith (Smith, 1994; Smith & Lim, 1995).

Smith's leaning model assumes a person on the nth step behind the barrier and a crowd inclined forward at an angle θ (see Figure A1.3). Each person can be assumed as a support for the person behind. Each person is subjected to a supporting force P_n from the front and to a counter-force P_{n-1} from behind. This can be offset by *h* (height) if people are at different heights (the terrain is not flat and there are steps). The person immediately on the barrier will transmit P_n to the barrier. Assuming N/m^2as the crowd density, then there are *Nw* people/unit length on each step. Smith's equation to calculate the force/unit length F_u is presented in Equation A1.1.

$$F_u = \frac{NwmH\sin\theta}{h}\left[\left[1+\frac{h}{H'\cos\theta}\right]^n - 1\right]$$ [Equation A1.1, (Smith, 1994)]

Where:

Nw is the number of people/unit length

w is the width of the step

m is the weight of the spectator

$H$is the centre of mass height

θ is the leaning angle of the crowd

h is the step height

H' is the Push height

A1.4.5.2 Results

Results are presented in this work using the people-evacuation time curves. In addition, a set of key percentages of evacuated population are highlighted, namely 25 %, 50 %, 75 %, 98 % and 100 % of the total number of attendees in the festival area. The choice of the percentages under consideration is based on the need to study the trend of evacuation with an interval of 25 % of the population as well as the analysis of the most sensitive part of the evacuation, the tail of the occupant-evacuation time curve (i.e. 98 % vs 100 %). The analysis of the people-evacuation time curves together with the selected percentages of evacuees allowed understanding the evacuation process and having a global picture on the impact of different cascading evacuation scenarios during the passage of time. It should also be noted that this analysis has also been coupled with the visualization interface embedded in the evacuation model Pathfinder, which visualizes the trajectories of each individual during the passage of

time. In addition to the analysis of the results provided by Pathfinder, this paper also considers the utility of Smith's leaning crowd model for the temporary stadium in the festival area.

Evacuation models generally embed stochastic variables or distributions to reproduce human behaviour during evacuation, e.g. delay time distributions, unimpeded walking speed distributions, etc. For this reason, it was necessary to define the appropriate number of runs to be simulated in order to avoid the results of the models being affected by the number of simulations performed (this is called *behavioural uncertainty* in the evacuation modelling literature (Ronchi, Reneke, & Peacock, 2014)). A convergence method (convergence in mean) was therefore employed to study the variability of model results due to the use of random sampling in the distributions. The method consisted of the analysis of the progressive average evacuation times produced by a consecutive number of runs. A measure of the convergence of two consecutive mean total evacuation times $TET_{avj}$is obtained calculating TET_{convj} (see Equation A1.2). It is expressed (in %) as the difference of two consecutive mean total evacuation times divided by the last mean evacuation time. This convergence measure assumes that the best approximation of the expected value (the mean total evacuation time) is the last mean evacuation time.

$$TET_{convj} = \left| \frac{TET_{avj} - TET_{avj-1}}{TET_{avj}} \right| \qquad \text{[Equation A1.2]}$$

In the present work, the runs were stopped when the error was lower than 1% for 5 consecutive runs, i.e., an additional run would change the results of less than 1% for five consecutive runs. A minimum number of 15 runs for each scenario were also considered.

<u>Scenario 1</u>

The average people-evacuation time curve of Scenario 1are presented in Figure A1.4 together with the evacuation times for 25 %, 50 %, 75 %, 98 % and 100 % of the festival population (see the red squares and corresponding percentages in Figure A1.4). It should be noted that the difference in evacuation times of the last 2% of the festival population (from 98 % to 100 %) is significantly higher than the difference between other percentages. In fact, 98 % of the population of this section of the festival area was evacuated within 803 s (approximately 13 min), while the average evacuation time of the entire population (i.e. 100 % of the population corresponding to 15,309 people) was 2319 s (approximately 39 min).

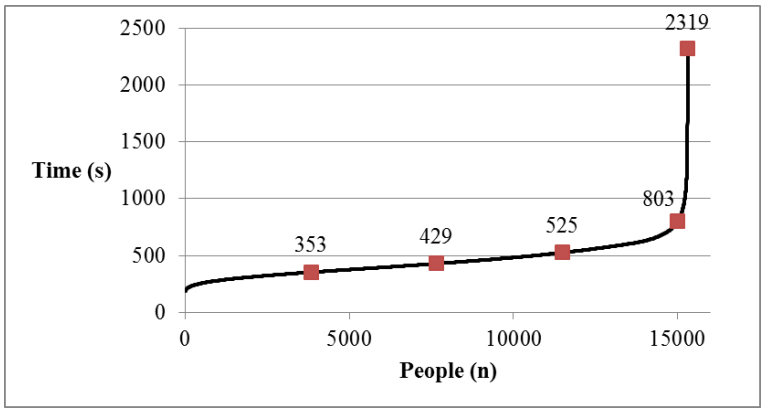

Figure A1.4 **People-evacuation time curve and percentages of evacuated population in Scenario 1. The x axis indicates the progressive number of people evacuated, while the y axis indicates the corresponding evacuation times. The squares indicates the time of the percentages of evacuated population (25 %= 353 s (5.9 min), 50 % = 429 s (4.1 min), 75 % = 525 s (8.75 min), 98 %= 803 s (13.4**

min), 100 % =2319 s (38.6 min)), while the curve is the people-evacuation time curve.

Scenario 1a

Scenario 1a is a benchmark scenario in which all conditions are similar to scenario 1 with the exception of the exit availability (all exits are available in this scenario). The average people-evacuation time curve and the percentages of evacuated population in Scenario 1a are presented in Figure A1.5.The 98 % of the population were evacuated within 675 s (approximately 11 min) while the average total evacuation time for the evacuation of 100 % of the population(15,309 people) was equal to 1463 s (approximately 24 min).

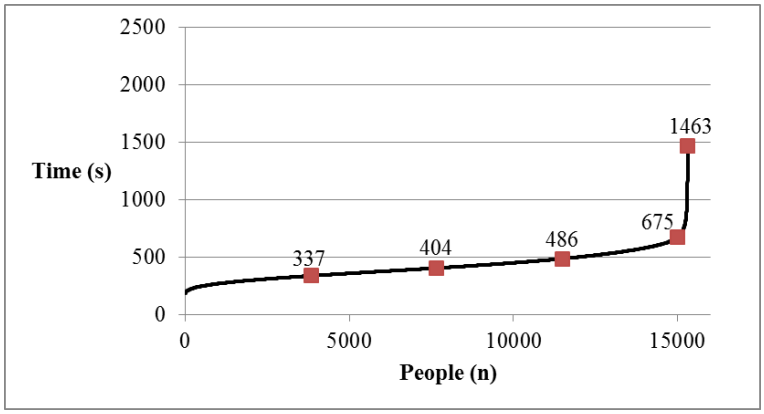

Figure A1.5 **People-evacuation time curve and percentages of evacuated population in Scenario 1a. The x axis indicates the progressive number of people evacuated, while the y axis indicates the corresponding evacuation times. The squares indicates the time of the percentages of evacuated population (25 %= 337 s (5.6 min), 50 % = 404 s (6.7 min), 75 % = 486 s (8.1 min), 98 %= 675 s (11.2 min), 100 % =1463 s (24.4 min)), while the curve is the people-evacuation time curve.**

Scenario 1b

Scenario 1b is a hypothetical scenario in which all conditions are similar to scenario 1 with the exception of an additional provisional exit available. The average people-evacuation time curve and corresponding percentages of evacuated population in Scenario 1bare presented in Figure A1.6. The 98 % of the population were evacuated within 767 s (approximately 13 min) and the average total evacuation time for the evacuation of 100 % of the population (15,309 people) was equal to 2020 s (approximately 34 min).

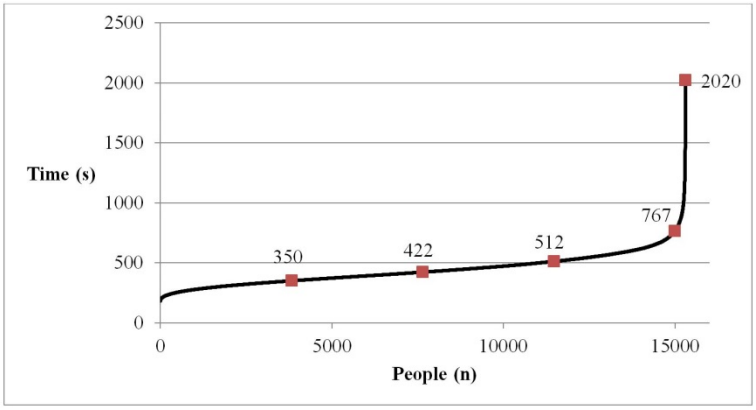

Figure A1.6 **People-evacuation time curve and percentages of evacuated population in Scenario 1b. The x axis indicates the progressive number of people evacuated, while the y axis indicates the corresponding evacuation times. The squares indicates the time of the percentages of evacuated population (25 %= 350 s (5.8 min), 50 % = 422 s (7.0 min), 75 % = 512 s (8.5 min), 98 %= 767 s (12.8 min), 100 % =2020 s (33.6 min)), while the curve is the people-evacuation time curve.**

Scenario 2

Figure A1.7 shows the people-evacuation time curve as well as the percentages of population evacuated for the cascading scenario 2 (seethe red squares and corresponding percentage in Figure A1.7). The curve in Figure 5 has an almost linear trend starting after the 25 % of the population is evacuated and there is no significant difference between the 98 % and 100 % of the population. Scenario 2 refers to the total evacuation of the entire festival area, corresponding to a total of 65,000 people evacuated in an average time equal to 5025 s (approximately 84 min), and the cause of the evacuation is a bomb threat.

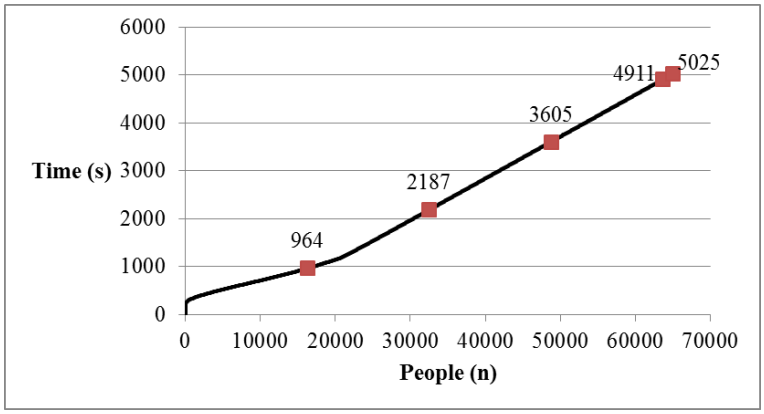

Figure A1.7 **People-evacuation time curve and percentages of evacuated population in Scenario 2.The x axis indicates the progressive number of people evacuated, while the y axis indicates the corresponding evacuation times. The squares indicates the time of the percentages of evacuated population (25 %= 964 s (15.8 min), 50 % = 2187 s (36.4 min), 75 % = 3605 s (60.0 min), 9 8%= 4911 s (81.8 min), 100 % =5025 s (83.7 min)), while the curve is the people-evacuation time curve.**

Scenario 3

The curve in Figure A1.8 shows the evacuation time in comparison with the progressive number of people evacuated in the cascading Scenario 3. Also in this case, the curve has a linear trend after the 25 % of the population is evacuated and no significant differences can be found between the 98 % and 100 % of the evacuated population. In Scenario 3 the average total evacuation is equal to 5009 s (approximately 84 min), and the cause of the evacuation is the threat of an explosion.

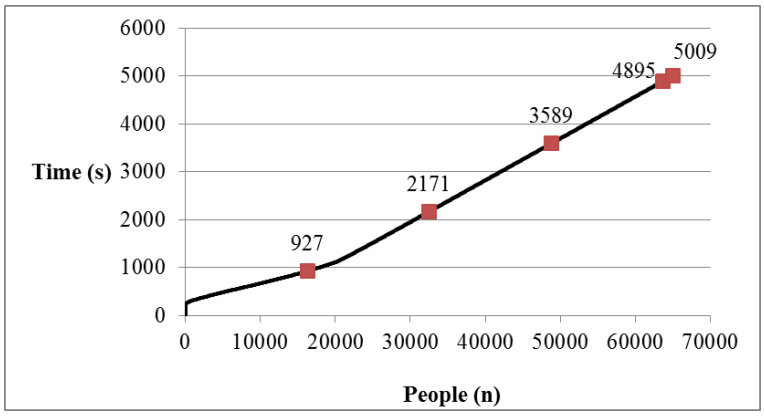

Figure A1.8 **People-evacuation time curve and percentages of evacuated population in Scenario 3.The x axis indicates the progressive number of people evacuated, while the y axis indicates the corresponding evacuation times. The squares indicates the time of the percentages of evacuated population (25 %= 927 s (15.4 min), 50 % = 2171 s (36.2 min), 75 % = 3589 s (59.8 min), 98 %= 4895 s (81.6 min), 100 % =5009 s (83.5 min)), while the curve is the people-evacuation time curve.**

Relative comparison of scenario results

The comparison of the results helped identify possible issues associated with cascading evacuation scenarios at music festival scenarios. The first evident conclusion from the comparison between scenario 1, 1a and 1b is that the number of available exits affects the total evacuation times. In fact, as expected, the average total evacuation time increases by approximately 37 % whenFin_Ex2, Fin_Ex3B and Fin_Ex3A not available (Scenario 1) when compared to the benchmark case where all exits are available (Scenario 1a). Similarly, comparing scenario 1 and 1b, the additional provisional exit in Scenario 1b causes a reduction of total evacuation time of approximately 5 min in scenario 1b (2319 s vs 2012 s, see Figure A1.9). This is the result of a re-distribution of exit usage given different available exits.

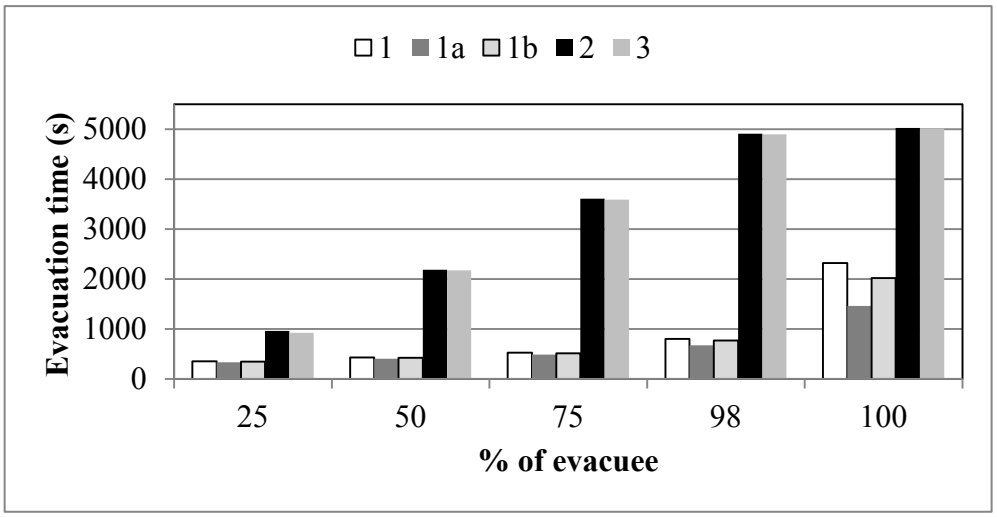

Figure A1.9 **Comparison of evacuation times for different scenarios and different % of evacuees.**

Another factor which may have an impact on the evacuation results is the average walked travel distance to the exit. This is also positively affected by the availability of more exits.

Another important conclusion is that the differences in terms of evacuation times for cascading scenarios 2 and 3 appear to be negligible (see Figure A1.9). This leads to the conclusion that if the cause of the evacuation scenario affects only the delay times, this would not lead to significant differences in the global people-evacuation time curve in large music festival scenarios in which the evacuation time is mostly dominated by flow constraints. In addition, if different initiators are represented through their impact on the same variable, the type of initiator itself would not be important, i.e., it is the effect of the initiator that matters rather than its nature. This can be further investigated analyzing the people-evacuation time curves. In fact, the people-evacuation time curves for Scenario 1, 1a and 1b have a different trend if compared with the corresponding curves for Scenarios 2 and 3. The curves of Scenario 1, 1a and 1b have an almost linear trend up to the point in which 98% of the population is evacuated, where instead the evacuation times increase significantly. The evacuation time of 100% of the population is approximately 2.9 times, 2.2 times and 2.6 times the evacuation time of 98% of the population in Scenarios 1, 1a and 1b respectively. This could be due to the impact of slow responders with high delay times, as well as people with temporary or permanent locomotion impairments (i.e., slow walking speeds), on the people-evacuation time curves. In contrast, the corresponding curves have an approximately linear trend in the cascading Scenarios 2 and 3 during the whole evacuation process, and present similar results although the delay distributions adopted for the population of the two scenarios are different (given the different causes of the cascading scenarios). This may be due to the fact that the flow through the exits is a predominant factor in the people-evacuation time curves, especially when compared with Scenarios 1 and 1a (where the delay times and walking speeds have a higher impact than flow constraints).

Crushing issues on the barriers in the stadium

Figure A1.10 represents the results obtained using the leaning model by Smith (1994) for the temporary stadium available in the festival area. Following the Green Guide (Department for Culture, 2008), the limit used to establish the maximum allowed force to avoid collapse of a barrier is 6 kN/m.

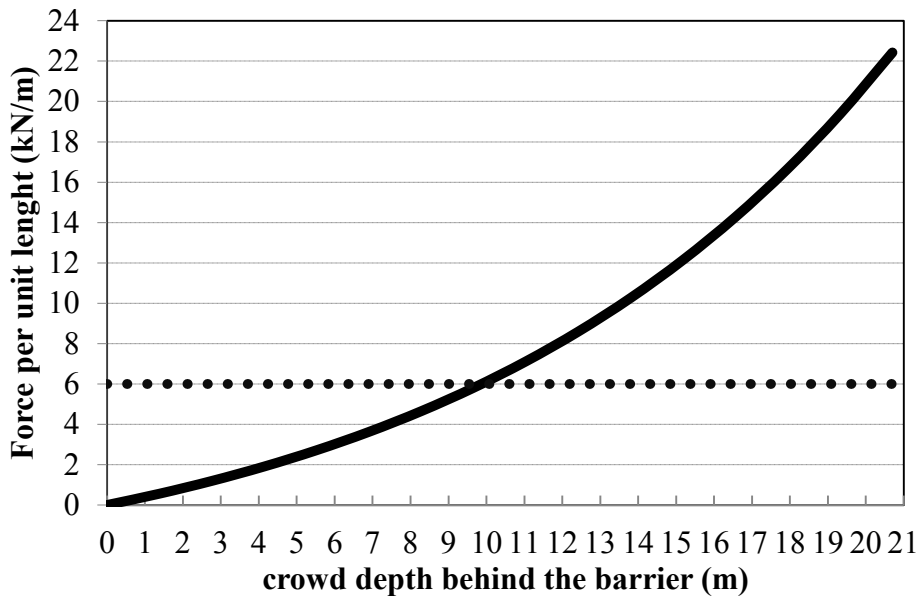

Figure A1.10 Results of Smith's leaning model on crowd pressure on barriers in the stadium.

According to the results in Figure A1.10, it can be seen that the force per unit length in this case study is higher than the threshold (dotted line in Figure A1.10 corresponding to 6 kN/m) at a distance around 10m. This value proves that a barrier can be located every seven steps of the stadium as this provides a crowd depth behind the barrier of 9.66m. However, in order to provide a safety margin, the barrier could be located at a lower number of steps (e.g., every 6 steps creating three separate areas with a maximum width of 8.28m).The results of the evacuation simulations could potentially be employed to perform estimations of the peak densities achieved during the evacuation and then apply the leaning model to design barrier spacing.

A1.5 Discussion

Evacuation modelling has been successfully employed to represent the evacuation process in case of different evacuation scenarios (including escalating and cascading effects) at a music festival. This study demonstrates the feasibility of using multi-agent evacuation models based on a continuous approach for large-scale evacuation scenarios. Existing research studies for such type of environments generally adopt simpler modelling assumptions, such as a macroscopic models and a cellular automata approach (Bandini et al., 2011; Kirchner & Schadschneider, 2002). This work represents one of the first attempts to use a multi-agent continuous evacuation simulation model for the study of large evacuating populations (greater than 50,000 people) at music festival including the case of escalating and cascading incidents. The benefits of multi-agent continuous models are the representation of crowd behaviours at an individual level and a more realistic estimation of people densities.

This study shows how multi-agent evacuation modelling tools are able to represent – either explicitly or implicitly – the behavioural factors that affect people's decision-making at music festival during cascading evacuation scenarios. The impact of different initiators can be simulated in evacuation models representing different behavioural responses (e.g. delay times) and adopting a gradual increasing of the area affected by the threat and the population involved.

An important finding of this study is that evacuation modelling can be used to identify the critical factors that affect evacuation processes under different conditions. This information can be used to help the relevant authorities and festival organizers adopt different measures that reduce evacuation times during cascading effect scenarios at music festivals.

Evacuation modelling allows a systematic evaluation of different evacuation scenarios, identifying the impact that different threats may have on the evacuation process. In this context, these models can also be used to evaluate different evacuation strategies, including the simulation of different levels of controls on the evacuation process (from a spontaneous people evacuation triggered by people's perception of a risk and social media to an evacuation procedure completely controlled by the music festival staff). The impact of decision makers' actions on crowd management can also be represented by controlling the assumed route choice and delay times of the evacuees. In this context, evacuation modelling tools allow for the evaluation of phased evacuation strategies (i.e. strategies in which different parts of the population are relocated at different times by the festival staff in order to optimize people flows and avoid congestions) and dynamic availability of exits (as demonstrated by scenario 1b in which an additional provisional exit has been assumed).

The model case study also demonstrated the effectiveness of evacuation models in investigating the impact of different number of exits upon the evacuation process, as well as their location. This information can be used at different stages of the crowd management process, such as the design stage (i.e. in order to optimize exit number and location) or for decision support (i.e., the negative impact of reducing the number of exit available in case of an emergency scenario can be predicted and actions can be taken accordingly). In particular, the use of evacuation modelling during the design of crowd safety of a festival gives the possibility to make thorough evaluation of the possible safety issues associated with evacuation if compared with the use of guidelines which generally provide running meters per number of attendees.

This paper suggests that the evaluation of the results of an evacuation model should include the entire people-evacuation time curves (and studying specific flows at different exits when deemed necessary) rather than just the total evacuation time. The reason is that the study of those curves can provide a more complete understanding on the evacuation process and give useful insights for possible counter-measures to avoid critical conditions.

It should be noted that this type of analysis of evacuation model results allows for the differentiation of the scenarios in relation to the factors affecting the evacuation process (e.g. flow through doors, congestion levels, delay times, walking speeds and travel distances, etc.). This can have positive implications for the counter-measures employed to solve critical conditions. For instance, scenarios in which flow constraints at doors are found to be crucial (e.g. scenario 1 and 1a in the model case study presented in this paper) can be addressed by intervening on the number, width and location of the exits (as shown in scenario 1b of the present model case study). The implementation of these modifications to the exits is fairly straightforward in music festival scenarios (especially when compared to buildings) since the delimitation of the space is (at least partially) generally done through movable fences. This

applies also to scenarios in which walking distances to the exits are found to be important. In addition, this issue may lead to consider the option to adopt modifications on the crowd management strategy.

In contrast, different types of intervention may be needed for those scenarios in which the delay times of the population play a key role in the total evacuation time. For example, these measures may require some modifications to the emergency notification strategy, changing the staff procedures for communicating with the festival attendees.

It should be noted that the use of an evacuation strategy that reduces the average total evacuation time does not necessarily lead to an increased level of safety. The overall exposure to a threat may increase even if the total evacuation time is shorter, i.e. a critical zone of the festival area could become more exposed to a threat for a longer time. Evacuation models generally produce not only numerical outputs concerning the evacuation times, flows and people densities, but they allow for the visualization of the entire evacuation process. This qualitative information (together with the people-evacuation time curve) can be used to identify the variation in threat exposure in light of different factors such as the adopted evacuation strategy, exit and route availability, behavioural assumptions, etc.

In general, music festivals have different characteristics in terms of people density compared to theatres or stadia, where each person has its own location assigned. It is therefore very important that the density of each area is calculated for the purposes of evacuation safety. Additionally, the use of evacuation model predictions of people densities allows for the consideration of the level of comfort experienced by the festival attendees at the site.

The use of safety crush barriers can help make attendees feel more comfortable, not only in the case of platforms made of steps (as analysed in this work), but also on flat surfaces. However, similarly to other aspects of evacuation, it is currently hard to find experimental data on this issue and the sub-models for the representation of the forces generated by a crowd are rarely implemented in evacuation simulation models (Harding et al., 2010). This is a limitation of the models, which should instead include the analysis of possible crushing issues on both platforms and flat surfaces. The present study suggests that the model proposed by Smith (1994) could be coupled with the analysis of the estimated peak densities calculated with an evacuation model. In this manner, it could be applied during the design phase of music festivals to guarantee the safety of the attendees and at the same time optimize the number of safety barriers required. Nevertheless, to date, only limited research has been carried out on the subject and the study of the level of comfort on safety crush barriers is rarely performed (Batty, Desyllas, & Duxbury, 2003; Lee & Hughes, 2005; Smith & Lim, 1995; Zhen et al., 2008).

This study demonstrates that the case of an initiator having multiple high-risk consequences associated with evacuation safety of citizens can be investigated with evacuation modelling tools. The present work represents an example of an effective use of evacuation modelling tools for assisting decision-making in case of incidents of different complexities, including cases in which escalating and cascading effects take place. For instance, the comparison between scenarios 1 and 1b demonstrates the possibilities of evacuation modelling for the evaluation of possible counter-measures to an evacuation incident and how an effective decision-making of emergency responders (scenario 1b in which an additional temporary exit has been provided) can positively affect evacuation safety. This work exemplifies this issue for the specific case of music festival scenario, but it is possible to extend the same principle to a variety of contexts in which large-scale evacuation may occur.

A1.6 Future Research

The present work analyses the use of evacuation models to produce estimates of the people-evacuation time curves in relation to different cascading evacuation scenarios. Future research could focus on the merging of this analysis with the study of the possible impact of the threat itself. For instance, if the threat has a direct impact on the evacuating population, e.g. the presence of a toxic cloud affecting people behaviour, there would be the need to directly simulate the impact on the evacuation process. In other words, the coupling of dispersion modelling, i.e. the prediction of gas concentrations caused by an explosion or a toxic release (Markiewicz, 2012), and people movement simulation should be the focus of future research, following existing examples for evacuation in enclosures (Korhonen & Hostikka, 2009).

The results of this paper show that there is a need to analyse in more depth the possible impact of the behaviours of the evacuees in the case of cascading scenarios. In this context, several variables merit further analysis, such as the training received by staff, their availability, population types (e.g. different percentages of people with locomotion impairments, people with different types of disabilities, etc.) and the number of attendees at festivals, etc.

Some of the input values used for the model variables have been based on scarce literature, thus future experimental data or on-site observations would significantly improve the reliability of model results. For instance, scarce information is available on the response times of both festival organizers and attendees in case of cascading evacuation scenario. This is also associated with the low frequency of actual emergencies in which cascading effects take place (Khakzad & Reniers, 2015), which often leads to extrapolate information from different types of events or drills. This problem can be partially solved by organizing large-scale (announced or un-announced) evacuation drills, although they are not common for such type of large-scale events.

A1.7 Conclusion

This work explored the use of a multi-agent continuous evacuation modelling approach to simulate cascading evacuation scenarios at music festivals. Evacuation models had sufficient flexibility to represent the behavioural aspects affecting the evacuation process during escalating cascading scenarios. In particular, the study of the people-evacuation time curves produced by evacuation models, coupled with the visual analysis of the evacuation process, allowed for the identification of the predominant factors affecting evacuation (e.g., delay times, flows through exits, etc.) and potential measures that could improve safety levels. Future research should focus on data collection on human behaviour, the inclusion of level of comfort analysis within evacuation models, a more advanced representation of vulnerable populations, and a coupled analysis of the impact of gas concentrations produced with a dispersion model and people movement and behaviours.

A1.8 Acknowledgments

This work is part of the Seventh Framework Programme EU project CascEff - Modelling of dependencies and cascading effects for emergency management in crisis situations, Grant agreement No:607665. The CascEff project aims to improve the emergency response in incidents that involve cascading effects. The authors wish to acknowledge the members of the project consortium. The authors also thank Bart Bruelemans, Wim Van de Vijver and Kris de Troch for their help in the definition of the festival model case study.The authors also thanks

Alexander Cedergren, Daniel Nilsson, Feng Xu and Anders Lönnermark for their review of the manuscript before publication.

A1.9 References

Alvear, D., Abreu, O., Cuesta, A., & Alonso, V. (2013).Decision support system for emergency management: Road tunnels. *Tunnelling and Underground Space Technology*, *34*, 13–21. http://doi.org/10.1016/j.tust.2012.10.005

Arthur, P., & Passini, R. (1992). *Wayfinding: people, signs, and architecture*.

Bandini, S., Rubagotti, F., Vizzari, G., & Shimura, K. (2011). A Cellular Automata Based Model for Pedestrian and Group Dynamics: Motivations and First Experiments. In V. Malyshkin (Ed.), *Parallel Computing Technologies* (Vol. 6873, pp. 125–139). Berlin, Heidelberg: Springer Berlin Heidelberg. Retrieved from http://link.springer.com/10.1007/978-3-642-23178-0_11

Batty, M., Desyllas, J., & Duxbury, E. (2003). Safety in Numbers? Modelling Crowds and Designing Control for the Notting Hill Carnival. *Urban Studies*, *40*(8), 1573–1590. http://doi.org/10.1080/0042098032000094432

Bellomo, N., & Dogbé, C. (2008). On the modelling crowd dynamics from scaling to hyperbolic macroscopic models. *Mathematical Models and Methods in Applied Sciences*, *18*(supp01), 1317–1345. http://doi.org/10.1142/S0218202508003054

Berlonghi, A. E. (1995). Understanding and planning for different spectator crowds. *Safety Science*, *18*(4), 239–247. http://doi.org/10.1016/0925-7535(94)00033-Y

Boyce, K. E., Shields, T. J., & Silcock, G. W. (1999). Toward the Characterization of Building Occupancies for Fire Safety Engineering: Prevalence, Type, and Mobility of Disabled People. *Fire Technology*, *35*(1), 35–50.

Boyce, K., Shields, T., & Silcock, G. (1999). Toward the characterization of building occupancies for fire safety engineering: Capabilities of disabled people moving horizontally and on an incline. *Fire Technology*, *35*(1), 51–67.

Branicki, L. J., & Agyei, D. A. (2015). unpacking the impacts of social media upon crisis communication and city evacuation. In *City Evacuations: An Interdisciplinary Approach* (pp. 21–37). Springer.

Bukowski, R., Peacock, R., & Jones, W. W. (1998). Sensitivity Examination of the airEXODUS1 Aircraft Evacuation Simulation Model (Vol. 16, pp. 1–14). Presented at the International Aircraft Fire and Cabin Safety Research Conference, Atlantic City, NJ (USA).

Cassa, C., Chunara, R., Mandl, K., & Brownstein, J. S. (2013). Twitter as a Sentinel in Emergency Situations: Lessons from the Boston Marathon Explosions. *PLoS Currents*. http://doi.org/10.1371/currents.dis.ad70cd1c8bc585e9470046cde334ee4b

Chapman, K. R., Carmichael, F. J., & Goode, J. E. (1982). Medical services for outdoor rock music festivals. *Canadian Medical Association Journal*, *126*(8), 935–938.

Chooramun, N. (2011). *Implementing a hybrid spatial discretisation within an agent based evacuation model*. University of Greenwich, London, UK.

Department for Culture, M. and S. (2008). *Guide to safety at sports grounds*. (Great Britain, Ed.). London: Stationary Office.

Elliott, D., & Smith, D. (1993). Football stadia disasters in the United Kingdom: learning from tragedy? *Organization & Environment*, *7*(3), 205–229. http://doi.org/10.1177/108602669300700304

Fahy, R. F., Proulx, G., & Aiman, L. (2012). Panic or not in fire: Clarifying the misconception. *Fire and Materials*, *36*(5-6), 328–338. http://doi.org/10.1002/fam.1083

Fruin, J. J. (1993). The causes and prevention of crowd disasters. Presented at the irst International Conference on Engineering for Crowd Safety, London, England.

Gwynne, S., Galea, E. R., Owen, M., Lawrence, P. J., & Filippidis, L. (1999). A review of the methodologies used in the computer simulation of evacuation from the built environment. *Building and Environment*, *34*(6), 741–749. http://doi.org/10.1016/S0360-1323(98)00057-2

Gwynne, S. M. V., Kuligowski, E., Spearpoint, M., & Ronchi, E. (2013). Bounding defaults in egress models. *Fire and Materials*. http://doi.org/10.1002/fam.2212

Gwynne, S. M. V., & Rosenbaum, E. (2008). Employing the Hydraulic Model in Assessing Emergency Movement. In *SFPE Hanbook of Fire Protection Engineering* (4th Edition). National Fire Protection Association, Quincy (MA): Di Nenno P. J.

Harding, P. J., Amos, M., & Gwynne, S. (2010). Prediction and Mitigation of Crush Conditions in Emergency Evacuations. In W. W. F. Klingsch, C. Rogsch, A. Schadschneider, & M. Schreckenberg (Eds.), *Pedestrian and Evacuation Dynamics 2008* (pp. 233–246). Berlin, Heidelberg: Springer Berlin Heidelberg. Retrieved from http://www.springerlink.com/index/10.1007/978-3-642-04504-2_18

Hart, P., Nilsson, N., & Raphael, B. (1968). A Formal Basis for the Heuristic Determination of Minimum Cost Paths. *IEEE Transactions on Systems Science and Cybernetics*, *4*(2), 100–107. http://doi.org/10.1109/TSSC.1968.300136

Health and Safety Executive. (1999). *The event safety guide: a guide to health, safety and welfare at music and similar events.* Norwich: HSE Books.

Helbing, D., & Molnár, P. (1995). Social force model for pedestrian dynamics. *Physical Review E*, *51*(5), 4282–4286. http://doi.org/10.1103/PhysRevE.51.4282

Helbing, D., & Mukerji, P. (2012). Crowd disasters as systemic failures: analysis of the Love Parade disaster. *EPJ Data Science*, *1*(1). http://doi.org/10.1140/epjds7

Johnson, G. (2006). Smoothing a Navigation Mesh Path (pp. 129–139). Presented at the AI Game Programming Wisdom 3.

Khakzad, N., & Reniers, G. (2015). Using graph theory to analyze the vulnerability of process plants in the context of cascading effects. *Reliability Engineering & System Safety*. http://doi.org/10.1016/j.ress.2015.04.015

Kirchner, A., & Schadschneider, A. (2002). Simulation of evacuation processes using a bionics-inspired cellular automaton model for pedestrian dynamics. *Physica A: Statistical Mechanics and Its Applications*, *312*(1-2), 260–276. http://doi.org/10.1016/S0378-4371(02)00857-9

Korhonen, T., & Hostikka, S. (2009). *Fire Dynamics Simulator with Evacuation: FDS+Evac Technical Reference and User's Guide* (Working paper No. 119) (p. 91). VTT Technical Research Center of Finland.

Krausz, B., & Bauckhage, C. (2012). Loveparade 2010: Automatic video analysis of a crowd disaster. *Computer Vision and Image Understanding*, *116*(3), 307–319. http://doi.org/10.1016/j.cviu.2011.08.006

Kuligowski, E. D. (2011). *Terror Defeated: Occupant Sensemaking, Decision-making and Protective Action in the 2001 World Trade Center Disaster*. University of Colorado at Boulder. Retrieved from http://books.google.se/books?id=9pNXMwEACAAJ

Kuligowski, E. D., & Mileti, D. S. (2009). Modeling pre-evacuation delay by occupants in World Trade Center Towers 1 and 2 on September 11, 2001. *Fire Safety Journal*, *44*(4), 487–496. http://doi.org/10.1016/j.firesaf.2008.10.001

Kuligowski, E. D., Peacock, R. D., & Averill, J. D. (2013). Modeling the Evacuation of the World Trade Center Towers on September 11, 2001. *Fire Technology*, *49*(1), 65–81. http://doi.org/10.1007/s10694-011-0240-y

Kuligowski, E. D., Peacock, R. D., & Hoskins, B. L. (2010). A Review of Building Evacuation Models, 2nd Edition, NIST Technical Note 1680. National Institute of Standards and Technology.

Lee, R. S., & Hughes, R. L. (2005). Exploring Trampling and Crushing in a Crowd. *Journal of Transportation Engineering*, *131*(8), 575–582. http://doi.org/10.1061/(ASCE)0733-947X(2005)131:8(575)

Lord, J., Meacham, B., Moore, A., Fahy, R., & Proulx, G. (2005). Guide for evaluating the predictive capabilities of computer egress models NIST GCR 06-886. National Institute of Standards and Technology. Retrieved from http://fire.nist.gov/bfrlpubs/fire05/PDF/f05156.pdf

Magnolo, E., Manenti, L., Manzoni, S., & Sartori, F. (2009). Towards a MAS Model for Crowd Simulation at Pop-Rock Concerts Exploiting Ontologies and Fuzzy Logic. In *Proc. of 10th workshop from Objects to Agents, WOA* (pp. 9–10). Citeseer.

Markiewicz, M. (2012). A Review of Mathematical Models for the Atmospheric Dispersion of Heavy Gases. Part I. A Classification of Models. *Ecological Chemistry and Engineering S*, *19*(3). http://doi.org/10.2478/v10216-011-0022-y

Moore, S. C., Flajšlik, M., Rosin, P. L., & Marshall, D. (2008). A particle model of crowd behavior: Exploring the relationship between alcohol, crowd dynamics and violence. *Aggression and Violent Behavior*, *13*(6), 413–422. http://doi.org/10.1016/j.avb.2008.06.004

Pan, X. (2009). *Computational modeling of human behavior for emergency egress analysis: a multi-agent based simulation approach.* Saarbrücken: Lambert Academic Publishing.

Pelechano, N., & Malkawi, A. (2008). Evacuation simulation models: Challenges in modeling high rise building evacuation with cellular automata approaches. *Automation in Construction*, *17*(4), 377–385. http://doi.org/10.1016/j.autcon.2007.06.005

Piccoli, B., & Tosin, A. (2011). Time-Evolving Measures and Macroscopic Modeling of Pedestrian Flow. *Archive for Rational Mechanics and Analysis*, *199*(3), 707–738. http://doi.org/10.1007/s00205-010-0366-y

Potts, L. (2014). *Social media in disaster response: how experience architects can build for participation*. New York: Routledge, Taylor & Francis Group.

Pretorius, M., Gwynne, S., & Galea, E. R. (2015). Large crowd modelling: an analysis of the Duisburg Love Parade disaster. *Fire and Materials*, *39*(4), 301–322. http://doi.org/10.1002/fam.2214

Proulx, G. (2002). Movement of People: The Evacuation Timing. In *SFPE Handbook of Fire Protection Engineering* (3rd edition, pp. 3–341 – 3–366 (Chapter 3–13)). Quincy, MA (USA): National Fire Protection Association.

Purser, D. A., & Bensilum, M. (2001). Quantification of behaviour for engineering design standards and escape time calculations. *Safety Science*, *38*(2), 157–182. http://doi.org/10.1016/S0925-7535(00)00066-7

Richards, C. E., & Wallis, D. N. (2005). Asphyxiation: a review. *Trauma*, *7*(1), 37–45. http://doi.org/10.1191/1460408605ta330oa

Roh, M.-I., & Ha, S. (2013). Advanced ship evacuation analysis using a cell-based simulation model. *Computers in Industry*, *64*(1), 80–89. http://doi.org/10.1016/j.compind.2012.10.004

Ronchi, E. (2013). Testing the predictive capabilities of evacuation models for tunnel fire safety analysis. *Safety Science*, *59*(0), 141–153. http://doi.org/10.1016/j.ssci.2013.05.008

Ronchi, E., Gwynne, S., & Purser, D. A. (2011). The impact of default settings on evacuation model results: a study of visibility conditions vs occupant walking speeds. Presented at the Advanced Research Workshop-Evacuation and Human Behaviour in Emergency Situations, Santander, Spain: Universidad de Cantabria, GIDAI.

Ronchi, E., & Kinsey, M. (2011). Evacuation models of the future: Insights from an online survey on user's experiences and needs (pp. 145–155). Presented at the Advanced Research Workshop Evacuation and Human Behaviour in Emergency Situations EVAC11, Santander, Spain: Capote, J. et al.

Ronchi, E., Kuligowski, E. D., Nilsson, D., Peacock, R. D., & Reneke, P. A. (2014). Assessing the Verification and Validation of Building Fire Evacuation Models. *Fire Technology*. http://doi.org/10.1007/s10694-014-0432-3

Ronchi, E., & Nilsson, D. (2014). Modelling total evacuation strategies for high-rise buildings. *Building Simulation*, *7*(1), 73–87. http://doi.org/10.1007/s12273-013-0132-9

Ronchi, E., & Nilsson, D. (2015). Basic Concepts and modelling methods. In *Evacuation modelling trends*.

Ronchi, E., Reneke, P. A., & Peacock, R. D. (2014). A Method for the Analysis of Behavioural Uncertainty in Evacuation Modelling. *Fire Technology*, *50*(6), 1545–1571. http://doi.org/10.1007/s10694-013-0352-7

Smith, R. A. (1994). The Hillsborough football disaster: Stress analysis and design codes for crush barriers. *Engineering Failure Analysis*, *1*(3), 183–192. http://doi.org/10.1016/1350-6307(94)90017-5

Smith, R. A., & Lim, L. B. (1995). Experiments to investigate the level of "comfortable" loads for people against crush barriers. *Safety Science*, *18*(4), 329–335. http://doi.org/10.1016/0925-7535(94)00052-5

Still, G. K. (2013). *Introduction to crowd science*. Boca Raton: CRC Press.

Thunderhead Engineering. (2014). Verification and Validation - Pathfinder 2014.3.

Wagner, N., & Agrawal, V. (2014). An agent-based simulation system for concert venue crowd evacuation modeling in the presence of a fire disaster. *Expert Systems with Applications*, *41*(6), 2807–2815. http://doi.org/10.1016/j.eswa.2013.10.013

Young, K. (1986). "The Killing Field": Themes in Mass Media Responses to the Heysel Stadium Riot. *International Review for the Sociology of Sport*, *21*(2-3), 253–266. http://doi.org/10.1177/101269028602100213

Zhen, W., Mao, L., & Yuan, Z. (2008). Analysis of trample disaster and a case study – Mihong bridge fatality in China in 2004. *Safety Science*, *46*(8), 1255–1270. http://doi.org/10.1016/j.ssci.2007.08.002