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Contents

Acknowledgements

***Luctor et Emergo* (Struggle and Rise)**

Luctor et Emergo is the motto of the Province of *Zeeland* where large parts of this study were conducted. The motto applies well to the theme of this study and my journey of writing a dissertation. I studied how organizations struggle with the intricacies of multidisciplinary emergency management and hope this contributed to our understanding of how to deal with disruptive events and create a more resilient, adversity-prone, and thriving society.

I can state confidently that the research has contributed to my own personal development. Doing a PhD is a life changing experience and I have learnt many lessons during my journey. I have struggled with the complexities of scientific research, the challenge of developing and maintaining a truly multidisciplinary research approach, and the culture of academia. I have struggled especially in the last part of my research when trying to combine a family, a full-time job, and writing the dissertation. It will probably take some time before I can see the true value of the lessons of the past few years. For now I simply enjoy the feeling that the struggling is done and the rising may come.

What I do realize already is that struggling is terrible without support. I am grateful to many people and I take this opportunity to say thanks those who supported me.

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Prologue
Searching for Resilience

The national, economical, and ecological security and well-being of industrialized nations depends on the reliable functioning of critical infrastructures. Infrastructure reliability is increasingly important but also increasingly difficult to ensure, given the growing complexity of infrastructural systems. The technological complexity of infrastructures grows as a result of the adoption of more advanced technology, the introduction of ICT or cyber components, and additional connections between different infrastructures. The organizational complexity of infrastructures increases because of the growing number and diversity of actors involved in the design, operation, and maintenance of infrastructures. Increasing technological and organizational complexity make it more difficult to anticipate adverse events and to plan for contingencies. Incidents that disrupt infrastructures are therefore more difficult to prevent and threaten the reliability of critical infrastructures.

Given the far-reaching consequences of infrastructure breakdowns, the question how to cope with increasing complexity is pertinent. In his book *Searching for Safety*, Aaron Wildavsky argues that we should try to anticipate risks that can be foreseen and prevented or mitigated, and to be resilient when unforeseen or non-preventable events occur (Wildavsky, 1988). Anticipation has been at the core of safety and security management for decades. Tools like threat assessment, risk analysis, hazard detection and prevention systems, and incident response plans have been developed and refined to anticipate risks as efficiently and effectively as possible. Our knowledge of how to anticipate risks, and the methods and tools for anticipating risks, are well developed and form the core of safety and security policies. But anticipation has its limits. The added value of risk assessments, preventive measures, and mitigation plans diminishes when the risk 'landscape' becomes more complex. When risks become too diverse and unpredictable, anticipation is no longer a viable and cost-effective strategy and a different quality is needed; the quality to 'bounce back' and recover from adversity, indifferent from the exact nature of the adversity. Being resilient and able to recover quickly is a more cost-effective strategy than anticipation and protection when being faced with uncertainty and complexity. And the risk landscape has become more complex in industrialized nations. The number of technological systems is growing rapidly, technology is becoming more advanced, and more connections between systems make that adverse events are more difficult to foresee. It is therefore no surprise that resilience is becoming a popular concept.

Besides being a popular concept, resilience is used to refer to more than just the ability to recover. The United Nations Office for Disaster Risk Reduction defines resilience as the ability of a system to "resist, absorb, accommodate to, and recover from the effects of a hazard in a timely and efficient manner" (UNISDR, 2015). The U.S. Presidential Policy Directive on Critical Infrastructure Security and Resilience speaks of the "ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions" (The White House, 2013). These definitions combine recovery with resisting or withstanding adverse events, aspects that have been set apart by Wildavsky as two *alternative* strategies for safety. The addition of more features to the concept of resilience is making resilience a more desirable quality but also makes the concept more difficult to understand.

While the concept of resilience is expanded in policy documents to include more desirable features, academic research generally sticks to a more narrow interpretation. A conceptual definition of resilience on a 'system' level is provided by Hollnagel, Woods, and Leveson (2006) who argue that resilience is the ability of a system to "recover, or to 'bounce back', after an adverse event, and to return to a normal state". This abstract definition of resilience applies to many fields like material science, ecology, and organizational science (Aguirre, 2006; de Bruijne, Boin, and van Eeten, 2010). In material science, resilience is used to describe the ability of a material to literally bounce back after being exposed to pressure. In ecology, resilience is used to describe the ability of ecosystems to regain their function(s) after a shock (like a drought, mass pollution, or the extinction of important species). And in organizational science, resilience has been defined as the 'maintenance of positive adjustment under challenging conditions' (Vogus & Sutcliffe, 2007, p. 3418). Providing a more concrete definition that makes it possible to recognize resilience in practice, in our case in the context of critical infrastructure recovery and reliability, is difficult. It requires a deep dive into the inner workings of a system. To describe the resilience of a physical substance, we must look into the structure and composition of the material – the atoms and molecules – to understand what its resilience is and how it comes about (Callister & Rethwisch, 2007). To understand ecosystem resilience, we must understand the regeneration of species, the interactions between species, and the dynamics of these interactions (Gunderson, 2000). To understand the resilience of a critical infrastructure, we have to dig into its ability to recover, the ease-of-recovery of the technical artefacts that make up the infrastructure and the actions and interactions of the actors – the infrastructure operators, emergency services, and other organizations – that come into action when the infrastructure is disrupted by an adverse event. We must understand how technical artefacts and actors interact when the system is disrupted in order to understand how the infrastructure is recovered and 'bounces back'. This deepening is rarely done when it comes to critical infrastructure resilience. Resilience often remains a somewhat superficial concept, presented as a desirable system-characteristic without further explanation of what it means to be resilient, what it takes to be(come) resilient, or what the costs of being resilient might be.

In chase of a ghost?

The concept of infrastructure resilience raises many questions. How does an infrastructural system 'bounce back' after an adverse and disruptive event? Does recovery take place as the result of a typical collection of actions, practices or mechanisms that we can refer to as resilience? Or is the response to every incident more or less unique and does the concept of resilience only imply a certain outcome? Does infrastructure resilience involve a standard process that we can identify in practice or is resilience only about outcomes and are we in chase of a ghost when it comes to the inner workings of resilience?

There is no consensus in the literature about what infrastructure resilience is and what it takes for an infrastructure to bounce back (Manyena, 2006; de Bruijne, Boin, and van Eeten, 2010). To understand what resilience is and how resilience comes about, it is necessary to look into the mechanisms that contribute to the recovery of an infrastructure after a disruptive event. Such mechanisms are found in different fields of research, including incident and emergency management, crisis management, and research on the operation of infrastructures and other complex systems. Incident and emergency management research has, for instance, focused on emergency decision-making, sensemaking, modes of coordination and incident command systems (ICSs) as explanations for why emergency response and recovery become effective or not (Granot, 1997; Kowalski-Trakofler, Vaught, and Scharf, 2003; Waugh Jr & Streib, 2006; Canton, 2007; Moynihan, 2009). Crisis management research has, among other things, addressed leadership, group and team performance, and modes of communication as explanations for effective response and recovery (Smith, 2000; Paul't Hart & Boin, 2001; Boin *et al.*, 2006; Comfort, 2007; Netten & van Someren, 2011). And research on the operation of infrastructures has focused on factors such as situational awareness, organizational structures, and inter-organizational coordination to explain effective incident response and recovery (Perrow, 1984; Schulman *et al.*, 2004; de Bruijne, 2006; Boin & McConnell, 2007; Perrow, 2007; Marti *et al.*, 2008; Roe & Schulman, 2008; Ansell, Boin, and Keller, 2010). The combined bodies of literature provide an abundance of potential processes and antecedents of effective infrastructure recovery, and it is difficult to see a pattern in the collective insights. The challenge of understanding infrastructure resilience – and proving that resilience is not only an outcome but also a process – therefore begins with obtaining an overview of these insights and developing an overarching framework that links different concepts as a basis for describing what resilience is and how it comes about (or not).

Riding the wave of virtualization

How to study infrastructure resilience? The response to events that disrupt infrastructures is notoriously difficult to study in practice. The unpredictable moments at which incidents occur and the dangers of emergency situations make it difficult, sometimes unethical, for researchers to observe incident response in real life. As a result, emergency management research is often based on after-action reviews or interviews with first responders, and on observations in simulated settings or during exercises. Such research has produced valuable insights but suffers from a few limitations. First, after-action reviews and reports provide accounts as recalled and reproduced by emergency responders. Such accounts can be distorted by flaws in the memory of responders (sometimes caused by the pressing conditions of emergency situations) or by the (un)intentional manipulation of information to make actions seem more logical in hindsight (Morrison & Meliza, 1999; Rudolph *et al.*, 2006). Emergency management studies that are based on direct observations form only a fraction of the total body of emergency management research. Second, it can be difficult to reconstruct an exact course of events from reports. Emergency response is hectic and fast and it can be difficult to trace how response processes enfolded (Woods, 1993). And third, both after-action reports and studies performed in simulated settings mainly involve single case studies and unique emergency scenarios. There is a shortage of systematic and comparative emergency management research.

Emergency management exercises have changed over the last decade. The increasing quality and decreasing costs of virtual reality software have made so-called 'virtual reality exercises' common practice for emergency services, at least in the Netherlands. Virtual reality exercises involve a virtual reality environment that presents an emergency situation that changes throughout the course of an emergency scenario and in response to actions and decisions of exercise participants. Virtual reality exercises are safe, economical as compared to real-life exercises, and offer the possibility to simulate every conceivable emergency situation. It is therefore no surprise that virtual reality exercises are popular. Virtual reality exercises also provide new opportunities for research. Virtual reality exercises especially provide an opportunity to overcome several of the common limitations of previous emergency management research. Virtual reality exercises are organized frequently, repeated with identical scenarios and settings but different participants, and make it possible to observe emergency responders in action from a close distance. This makes virtual reality exercises suitable for direct observational research and comparative analysis. We seize upon the opportunity with a systematic and comparative analysis of emergency response in virtual reality exercises that revolve around the multidisciplinary management of emergencies that disrupt critical infrastructures.

Chapter 1
Introduction

1.1 Introduction

Research problem

Understanding resilience is key to understanding and enhancing the reliability of infrastructures in a complex environment. Resilience is notoriously difficult to define as it includes the abilities to withstand and recover from incidents, and to become better as a result of disruptions. To specify and explain resilience in the context of infrastructure reliability, we focus on the ability to recover from disruptive incidents. To understand and potentially enhance resilience, we must first be able to explain how fast and effective recovery from disruptive incidents comes about (Rothery, 2005).

Recovery of infrastructures that are disrupted because of incidents is part of emergency management. Emergency management, the processes and procedures through which emergency services and other organizations cope with incidents, forms the inner working of infrastructure recovery. Infrastructure recovery is one of multiple objectives of operational emergency response – such as providing medical care, evacuation of a local population, or dealing with hazardous materials – depending on the nature of the incident. The recovery of disrupted infrastructures is part of a larger, multi-process and multi-objective, emergency response effort. Given the many objectives of emergency response, the management of emergencies varies in terms of performance, i.e. the extent in which different objectives are prioritized and achieved. The speed and effectiveness by which emergency response objectives are achieved are determined by factors in the processes of emergency management. To understand what objectives are prioritized and achieved in a comprehensive emergency response effort, it is necessary to identify and understand the processes and procedures that contribute to the prioritization and achievement of emergency management objectives.

To understand emergency management performance, and particularly how fast and effective infrastructure recovery comes about, we must understand what emergency services and infrastructure operators do to coordinate and achieve procedures and objectives. There is a theoretical knowledge gap when it comes to such understanding. Existing emergency management research provides many insights in the effectiveness and failures of emergency response but does not take into account the increasing technological and organizational complexity that dominate contemporary emergency management. Technological complexity makes that emergency response involves more – and more difficult – tasks and objectives and that technology experts are indispensable to manage an emergency situation. The growing number of actors and variation in types of actors involved in emergency response make that the organization of emergency response becomes more challenging. Moreover, contemporary emergency management is characterized by an increasing urgency to limit the effects of an emergency on its surroundings. The growing impact of emergencies in terms of economic losses increases the importance to mitigate the effects and limit the consequences of incidents. Whereas these trends have their effects on how effective emergency response and recovery come about, they have not received much attention in emergency management research thus far.

Relevance

There are three main reasons why research on resilience with a focus on recovery is important. First, we need to develop and test a framework that describes the inner workings of resilience to make sure that the concept of resilience obtains more meaning and that the discussion on what constitutes resilience can evolve on basis of concrete hypotheses. Resilience is a much used concept in policy discussions on safety and security but the concept must become more concrete to obtain practical meaning and maintain its relevance. Second, we must understand the effects of trends like increasing technological and organizational complexity and increasing pressure to recover disrupted infrastructures on emergency management in practice. The nature of emergencies is changing and the practice of emergency management changes accordingly. However, much of what we know about emergency management stems from times in which complex technology was less ubiquitous, traditional emergency services where the only or main actors at an emergency scene, and infrastructure recovery was a less important emergency management objective. And third, we need to understand the factors that enable effective emergency response to improve the effectiveness of emergency management and thereby increase resilience.

Questions

The central questions in this study are: (i) how do emergency response actors coordinate multiple emergency management objectives and procedures, and (ii) how does the way they do this determine emergency management performance?

We formulate six research questions to work systematically towards an answer to the central questions. Research questions one to three address the theoretical and methodological approach:

- RQ 1. What are the important factors in the process of emergency response that determine emergency management performance, and how can these factors be combined into an analytical research framework? (Chapter 2)
- RQ 2. How can the important factors in the process of emergency response and emergency management performance be studied during virtual reality exercises? (Chapter 3)

RQ 3. How can the important factors in the process of emergency response and emergency management performance be operationalized for empirical observation and comparative analysis? (Chapter 4)

Research questions four to six guide the empirical part of the research:

RQ 4. What variation is observed in emergency management performance? (Chapter 5)

RQ 5. To what extent and in what manner do emergency response actors communicate during emergency response, and how does this affect emergency management performance? (Chapter 6)

RQ 6. What (inter)actions of emergency response actors inhibit or support emergency management performance, and how does this influence infrastructure recovery? (Chapter 7)

1.2 General approach

This research can be qualified as an analytical study with a methodological component. The study is above all analytical as our aim is to dissect the operational response to emergencies in order to find the processes that determine emergency management effectiveness and the degree in which different emergency management objectives are reached. The methodological component relates to the decision to study emergency response in virtual reality exercises and the choice of research methods, that is: video-observations and communication network analysis. The methodological component of the research is not treated as an objective in the research design but we reflect upon the value of virtual reality exercises and the applied research methods when we discuss recommendations and questions for future research.

Research objective

Our main research challenge is to specify and explain how infrastructure resilience comes about. The point of departure for this study is the notion that the management of emergencies or other adverse events forms the inner working of infrastructure resilience. This means that in order to understand how resilience comes about, we need to be able to explain variation in emergency management performance. We must understand how effective emergency response comes about and what factors determine the degree in which emergency management objectives in general, and infrastructure recovery in particular, receive attention during the response to emergencies. By systematically studying the emergency response processes that determine emergency management performance, we aim to develop an integrated set of concepts or practices – a conceptual framework – that helps explain variation in emergency management performance. The conceptual framework needs to identify the important factors that contribute to emergency management performance and specify how the identified factors affect emergency management performance.

Understanding emergency management: processes and performance

We develop an analytical research framework of operational emergency management performance. The framework builds upon previous research on emergency management, crisis management, team performance, and literature on high-reliability organizations. To understand how emergency management performance comes about we focus on processes of emergency management. These processes, consisting of actions of emergency response actors and interactions between emergency response actors, determine whether and how effective emergency response and recovery come about. We start with a selection of processes that are prominent in the literature: situational awareness, emergent coordination, collective sensemaking, and emergency decision-making.

Emergency management performance is conceptualized and assessed as a multilevel and multi-faceted outcome. To accommodate the many-sidedness of performance, a performance composite is developed that includes performance at different levels of emergency response and performance in terms of outcomes and in terms of actor-satisfaction.

Emergency management processes and emergency management performance are integrated into an analytical framework to explain how emergency management performance comes about. The framework forms the starting point for our empirical research. The framework uses several concepts from previous research to explain emergency management performance. In addition, we identify new emergency response processes that are systematically associated with emergency management performance. The research is therefore both explanatory and exploratory.

Comparative analysis

The empirical part of the research consists of a comparative analysis of emergency response processes and emergency management performance. Twenty virtual reality exercises in which an operational, multidisciplinary emergency management team responds to an emergency scenario. The emergency response is analyzed by use of a mixed methods research design that combines a quantitative analysis of communication networks and the qualitative analysis of video-observations of emergency responders in action. The quantitative analysis is used to relate measurable, structural characteristics of the emergency response to emergency management performance. Moreover, the outcomes of the communication network analysis are used to purposefully select cases for further in-depth, qualitative research. The qualitative analysis builds upon the outcomes of the quantitative analysis and traces the processes through which emergency management performance comes about.

1.3 Scope, validity and limitations

The scope of the research and the research approach have consequences for the validity and generalizability of the research findings. The research is performed in one specific Safety Region in the Netherlands[1]. The exercise scenarios involve three types of critical infrastructures: road networks with a major tunnel, railways, and waterways. The exercises focus on the operational level of emergency response and are performed with one type of virtual reality simulation technology[2]. What is found to work in the Dutch Incident Command System and emergency management practice cannot be transferred to emergency response in other countries without considering the differences between incident command systems. What is found with regard to the three infrastructures that are part of this study cannot be transferred to other infrastructures without considering the specific technical challenges involved in recovery of these infrastructures. What is observed at the operational level of emergency response cannot be translated to higher levels of coordination, or crisis management in general, without considering the differences between tasks and conditions at different levels of emergency management. And what is found with regard to the instant response to emergencies cannot be transferred to other phases of emergency management like prevention, preparation, or recovery without considering the differences between tasks, conditions and the actors involved in different phases. The findings provide relevant insights in the nature of emergency management, how we can prepare for emergency response, and how we can study emergency management in action but when our findings are transferred to other settings it must be done with care and consideration of the differences between the specific setting in which this research is performed and the settings to which findings are transferred.

There are two more specific limitations to the generalizability of the research findings. First, the fact that the research is performed in simulated settings has consequences for the external validity of our findings. Although virtual reality exercises are complete in the sense that all physical objects are represented virtually, several none physical aspects are missing. The degree of chaos and the physical difficulties that characterize the early stages of emergency response are to a lesser degree present in virtual reality exercises. There are no loud noises[3], there is no emotional or aggressive counterplay from victims or others involved in the emergency, and there are no inconvenient physical aspects like smoke, heat, or a lack of light. Virtual reality exercises are 'clinical' as compared to the messiness of real-world emergency scenes. The absence of messy aspects makes that emergency response is physically more convenient in virtual reality exercises than in real world emergency situations. Virtual reality exercises can be described as naturalistic

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[1] See chapter two for an explanation of Safety Regions and the Dutch Incident Command System.

[2] The XVR virtual reality training software of E-Semble BV.

[3] Although the noise of the Westerschelde tunnel ventilation system is reproduced during exercises to practice communications with the tunnel operator to switch of vans around an emergency location.

(Schaafstal, Johnston, and Oser, 2001), as most real world objects are present, but not as natural settings since important non-physical emergency response phenomena are missing. This difference is likely to have an effect on the authenticity of the behavior of emergency response actors during the exercises. The clinical setting of virtual reality exercises allows emergency response actors to deliberate their actions in relative peace. Response processes and patterns that relate to time and other forms of pressure are likely to be more common and intensive in reality where actors have little time to deliberate their actions. Overall, this means that the relative calmness of the simulated research setting must be considered when research findings are to be generalized to other settings. Second, the fact that the virtual reality exercises do not involve actual frontline units – the personnel that executes the response tasks - limits the insights of our findings for understanding emergency management effectiveness. Research has shown that control over frontline units by emergency response commanders is limited (Groenendaal & Helsloot, 2015). All commands are expected to be executed in virtual reality exercises whereas in practice they can be ignored or altered by frontline units. This is an influential factor for understanding emergency management effectiveness that is disregarded in this study.

With a mixed methods research design that combines multiple research methods, we aim to bring rigor in the analysis of emergency management processes and performance and increase the internal validity of the research. However, there are two limitations to our research. First, as with all observational research, the drawback of video-based analysis is the difficulty of gaining understanding of why actors make specific choices and to deduct the motivation behind observed behavior (Creswell & Miller, 2000). Actors cannot immediately be asked for the reasons behind their actions since the analysis of video recordings can take place days, sometimes weeks after a recoding is made. We interviewed several emergency responders and exercise facilitators to discuss specific actions and interactions that were difficult to understand but some situations could not be cleared up. Second, a limitation of combining communication network analysis and video-observations is that the two methods do not necessarily analyze the same concepts. This difficulty relates to the issue of concept stretch; the use of a single concept for specific, concrete, measureable phenomena and more fuzzy, broader, qualitative phenomena (Onwuegbuzie, Bustamante, and Nelson, 2010). Concept stretch is a much discussed topic in the literature on mixed methods research. Concept stretch is relevant for concepts like communication and coordination that need to be explicitly detached to distinguish the objective measurement of interaction – communication – from the qualitative analysis of interaction – the research on coordinative practices. The concepts must be clearly separated to avoid stretching the concept of communication to include coordination and reducing coordination to communication. This is not only relevant during the empirical analysis but also, or even more, during the integration of research findings where it is all too easy to transfer insights gained with regard to a specific concept like communication to the broader concept of coordination. Most importantly, what is measured is different from what is studied qualitatively but combining methods provides a rich and systematic account of emergency management that cannot be obtained by using methods separately.

1.4 Thesis outline

The structure and contents of this thesis are schematically shown in figure 1. This thesis consists of two parts. Part one describes the research approach, including the concepts and theories used, the research setting and cases, and the research design and methods applied. Part one includes three chapters:

Chapter two presents a review of the literature on emergency management, crisis management, team performance, and the operation of complex technical systems. Based on insights from different bodies of research, an analytical research framework is developed to explain emergency management performance. The framework is discussed in the context of emergency management in the Netherlands and the Dutch Incident Command System.

Chapter three introduces virtual reality exercises as the setting of our research. The rise and nature of virtual reality exercises is described and we discuss why virtual reality exercises form an opportunity for research. The chapter continuous by introducing the research setting in Safety Region Zeeland and the four exercise scenarios that are part of this study.

Chapter four presents the study design and methodology. We explain how a mixed methods research design helps to perform a comparative and systematic analysis of operational emergency management and how data from virtual reality exercises is collected and analyzed. The analytical framework is operationalized as we explain how communication network analysis, video-observations and multilevel task scores are used to study emergency management processes and performance. Operationalization of the analytical framework results in a set of hypotheses that link the research methods with the analytical framework and form the point of departure for the empirical research.

Part two of the thesis presents the empirical research; the emergency management performance and processes observed in the exercises. Part two consists of three chapters:

Chapter five describes the emergency management performance observed in the exercise. Performance is described at the level of emergency response tasks, actors, multidisciplinary subgroups, and on-scene command teams as a whole. We present relations between performance at different performance levels, discuss the observed performance in the light of exercise scenario characteristics, and reflect on the relation between performance and actor satisfaction.

Chapter six presents the outcomes of the emergency response communication network analysis and links the outcomes to emergency management performance. The chapter is structured along three core concepts in our analytical framework: situational awareness, emergent coordination, and collective sensemaking. We discuss what the outcomes of the communication network analysis reveal about the role of each concept for emergency management performance. The chapter closes with a discussion of key insights and interesting cases for further analysis.

Chapter seven describes the outcomes of our analysis of video observations. The chapter builds on the insights from the communication network analysis. The chapter is structured along the four concepts that make up our analytical framework: situational awareness, collective sensemaking, (emergent) coordination, and emergency decision-making. The role of each concept for explaining how emergency management performance comes about is discussed with regard to emergency response in the field and during on-scene command team meetings. The chapter concludes with a discussion of the effects of the factors observed on emergency management performance.

The last two chapters of this thesis are dedicated to insights and recommendations. **Chapter eight** provides the conclusion of the research by answering our two main questions. The chapter provides an overview of outcomes and combines the outcomes to present a new and better conceptual framework for understanding how emergency management performance comes about. We finish off with an **epilogue** in which we provide recommendations for emergency management in critical infrastructures and questions for further research. The epilogue focuses on three questions: how to be resilient? How to become resilient? And how to identify resilience?

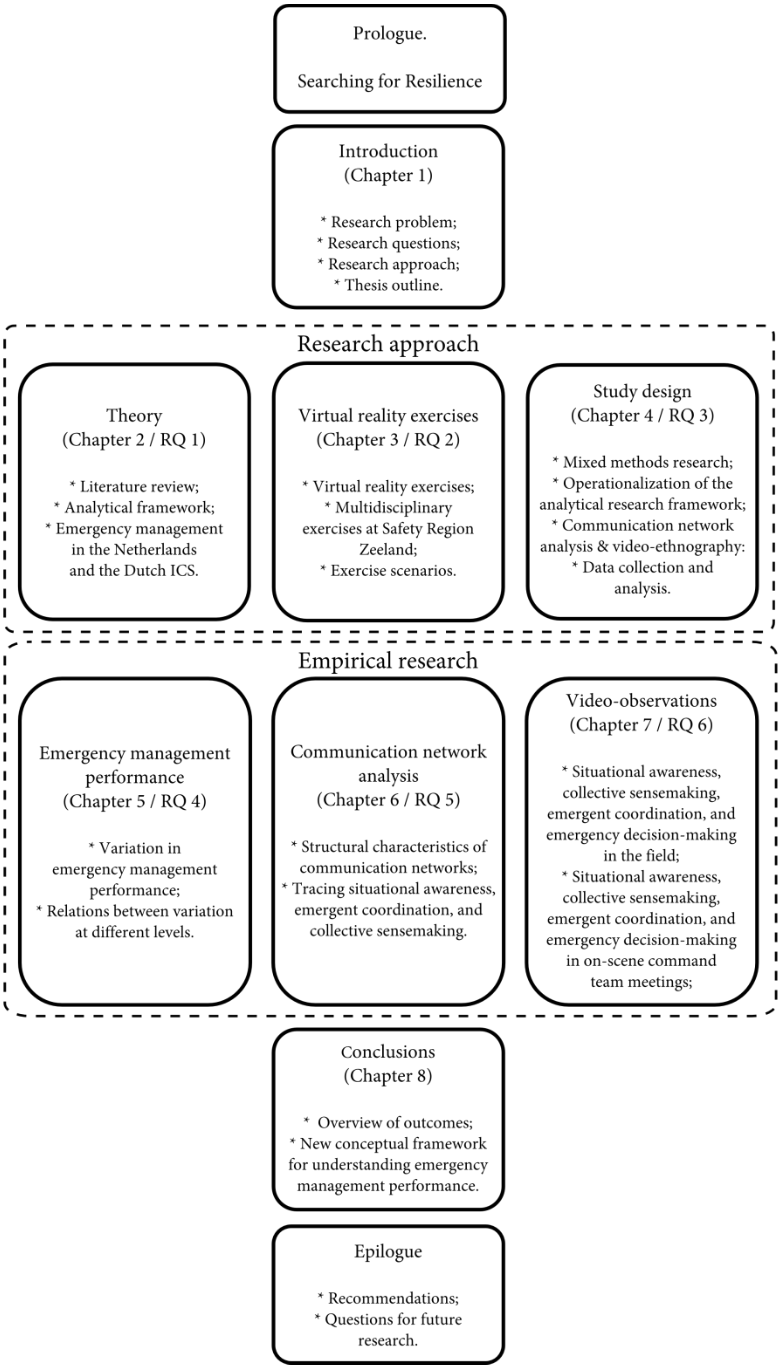


Figure 1 - Thesis outline

Chapter 2
An analytical framework for emergency management performance

2.1 Introduction

Operational emergency management is central to the resilience of society but understanding of how effective multidisciplinary emergency management comes about is limited. The driving question in this chapter is: What are the important factors in the process of emergency response that determine emergency management performance, and how can these factors be combined into an analytical research framework?

Operational emergency management is a complex combination of tasks, actors, administrative arrangements and coordinative structures. We start with an introduction to the nature of operational emergency management to shed light on this complexity. We then discuss the literature to see what research has been done previously on emergency management and what concepts and theories exist that explain variation in emergency management performance. Previous research on emergency management is fragmented and the complexity of operational emergency management makes that concepts that explain variation in performance come from different bodies of literature. Our next challenge is therefore to explain how different concepts can be integrated to provide a comprehensive analytical framework to guide the empirical investigation of this study. Since the organization of operational emergency management varies between countries, our last challenge is to explain how operational emergency management is organized in the Netherlands and how our analytical framework relates to the Dutch Incident Command System.

The chapter is structured as follows. Section 2.2 introduces operational emergency management. Section 2.3 discusses concepts and theories that explain variation in operational emergency management performance, dealing consecutively with coordination, crisis conditions, teamwork, and the way emergency management performance is commonly conceptualized in the literature. The different theoretical perspectives are integrated to form an analytical research framework in section 2.4. Section 2.5 describes how the analytical research framework applies to emergency management in the Netherlands.

2.2 Operational emergency management

Before we can discuss the factors that determine the effectiveness of operational emergency management, we need to set out what operational emergency management is about. Operational emergency management is primarily about the execution and coordination of emergency response tasks. Emergencies generally require multiple tasks to be performed simultaneously (Hillyard, 2000). Firefighting, containing hazardous materials, rescuing victims, transporting victims to safe locations, forensic research, and cleaning of emergency sites are examples of common tasks in emergency management. When the scale of an emergency increases, it is likely that not only the scale of the tasks but also their variety increases (Molino Sr, 2006). This variety of tasks is taken care of by multiple emergency response actors that coordinate emergency response tasks in different ways.

The execution and coordination of emergency response tasks is strongly influenced by the conditions under which emergency management takes place. The conditions of operational emergency management are characterized by crisis conditions. These conditions involve threat, uncertainty, and urgency. The threat stems from the damage that an emergency inflicts on people, goods, local surroundings, and possibly a larger effect area. The threat is imminent and often increases when emergency services do not respond quickly and effectively. Emergencies are uncertain situations. Initially, this uncertainty stems from a lack of information on the situation. It takes time to establish a comprehensive understanding of an emergency situation. But even when the situation is more or less clear, emergency response actors require continuous situational updates to maintain awareness of the status and effectiveness of the emergency response. Urgency stems from the threat and damage that increase when not acted upon immediately. An environment characterized by crisis conditions makes operational emergency management a challenging task. Imminent threat creates an urgency to act while uncertainty makes it difficult to decide how to act.

Operational emergency management is a multi-actor endeavor. Different organizations become involved in the response to an emergency, depending on the characteristics of an emergency situation. These organizations can be public (emergency services and local authorities), semi-public (rescue organizations), or private (infrastructure operators, local industries). Emergency management is a core task for some of these organizations and a parallel or completely ad hoc task for others (Zanders, 2008). The composition of operational emergency management organizations varies as well. Operational response organizations are generally composed of a standard core of representatives from emergency services and the local municipality and a group of optional members that can become part of the team when useful (Lindell, Perry, and Prater, 2005). Operational emergency management takes place in the field as well as in meetings of operational emergency responders at emergency sites. Operational emergency management involves coordination, operational decision-making and the orchestrating and synchronizing of operational activities (van Dijkman & van Duin, 2006). Practically, this means deciding on what tasks to execute, when to execute them, and who will be involved in the execution. Operational coordination can take place in the field. Emergency response actors look each other up in the field to coordinate emergency response tasks on the spot. Such emergent coordination is relevant to organize and align multidisciplinary and interrelated monodisciplinary tasks quickly. Operational, or on-scene command teams commonly form the official platform for the integral coordination of emergency response. On-scene command teams meet to make sure that emergency response tasks are taken care of, that priority is given to the right aspects of an emergency, and that emergency response tasks can run simultaneously without friction or misunderstandings between different emergency services.

The effectiveness and quality of emergency management can be assessed in different ways. To understand how infrastructure recovery is managed as part of emergency response we are mainly interested in operational emergency management effectiveness. Operational emergency management is about the execution and coordination of emergency response tasks. The execution of response tasks is done by emergency management disciplines, either individually or as collaboration between multiple disciplines. Coordination of response tasks emerges in the field between specific emergency disciplines or collectively in on-scene command team meetings. Task execution and coordination represent two aspects of operational emergency management for which performance can be assessed. The efficiency and effectiveness of the execution of emergency response tasks can be assessed. It is possible for both mono- and multidisciplinary tasks to determine the extent to which results are achieved and the time it takes to achieve results. Such an outcomes oriented approach focuses on what has been achieved. The fact that outcomes can be observed creates an opportunity to assess operational emergency management performance in a more or less objective way. Another approach focuses on emergency management processes. A process approach focuses on *how* outcomes are achieved. This may include the quality of coordination processes like situational assessment and emergency decision-making or the manner in which emergency response tasks are executed. Processes require more intensive observation than outcomes and a longitudinal approach. How emergency management processes run does also influence how emergency response actors experience the emergency response. Performance in terms of emergency management processes can therefore also be assessed through the subjective experience of emergency response actors. Whether emergency management processes take place according to expectations, and whether emergency response actors can participate as much as they like, is likely to affect how satisfied actors are with how the response to an emergency has evolved. Operational emergency management is a matter of achieving outcomes through coordination processes and both aspects can serve to assess performance.

In short, operational emergency management concerns the execution and coordination of emergency response tasks by multiple actors, often under harsh conditions.

Operational emergency management performance can be assessed in terms of effectiveness or the degree in which objectives are achieved and in terms of the quality of the process through which results are obtained.

2.3 Factors that contribute to effective emergency management

What determines the success of operational emergency management? The answer to this question stems from different fields of research and is therefore found in different bodies of literature. To develop a comprehensive view of what drives operational emergency management performance, different approaches must be integrated. This section presents factors that are commonly presented in the literature as enablers of emergency management performance (2.3.1) and explains how the crisis-like conditions influence operational emergency management (2.3.2). We continue by discussing factors that enable effective teamwork as operational emergency management typically involves teams (2.3.3). The section concludes with a discussion of performance in the context of operational emergency management (2.3.4).

2.3.1 Coordinating operational emergency response

Emergency management research has produced an impressive array of factors that influence emergency management effectiveness. This section presents an overview of frequently used factors. We start with information exchange and communication as the foundations of coordination. We continue by introducing sensemaking and situation awareness that explain how information is used to coordinate emergency response. We address the multi-actor, organizational setting of operational emergency management and the necessity to organize emergency management capacity at emergency locations. The overview finishes with emergency decision-making as the process of making the right choices under difficult and uncertain conditions.

Information and communication: the building blocks of coordination

Information exchange and communication are core concepts in research on emergency management. Communication problems have frequently been found to explain failures in emergency response (Dunn, Lewandowsky, and Kirsner, 2002; Manoj & Baker, 2007). Communication research generally focuses on errors in the communication between emergency response actors and the resulting misunderstandings. Information exchange research is mostly oriented at the spread of information over emergency response organizations and explains failures through a lack of information at critical locations or actors (Hinsz, Tindale, and Vollrath, 1997; Bergström *et al.*, 2010).

The focus of information exchange research in emergency management settings is often placed on the role of information processing technology. The rapid development of information technology has resulted in a surge of research on support tools for information processing emergency management (Bharosa, Appelman, and de Bruin, 2007; Carver &

Turoff, 2007; Granlund *et al.*, 2010; Schraagen, Veld, and De Koning, 2010). Gonzalez (2008) shows how newly introduced information technology supports coordination during emergency response. Netten & van Someren (2011) presented and tested a method to increase communication efficiency during emergency response. And the role of information managers in the use of information during emergencies has been studied by Bharosa, Appelman, and de Bruin (2007). A main branch of this research is dedicated to network centric (netcentric) operations (NCO). The idea of netcentric operations originated in the military where it was initiated as netcentric warfare. The idea of netcentric operations is that available information is shared throughout an organization, both horizontally and vertically (Van De Ven *et al.*, 2008). Although NCO is often presented as a technological innovation, it is essentially an organizational approach to information exchange instead of a technological feature. In NCO, information is made available to all actors instead of exclusively exchanged between a limited number of actors. This means that information is available to actors without having to send a request first (McGrath & McGrath, 2005). The claimed benefits of NCO are improved decision-making and potential self-synchronization of organizational units. Decision-making can be improved as information becomes more accurate – the reasoning behind this is that incorrect information is more quickly corrected when it becomes available to an entire organization – and more readily available to actors (Von Lubitz, Beakley, and Patricelli, 2008). Organizational self-synchronization originates when organizational sub-units have similar information at their disposal (Alberts & Hayes, 2007). Similar information will result in a synchronization of efforts.

Research on communication and information exchange is about getting the right information, at the right place in the emergency response organization, at the right time and about the technology and arrangements that prevent this or make this possible. Information exchange and communication are key factors in understanding operational emergency management, and thereby on-scene command team performance. Information exchange deserves a central role in the development of a framework for understanding operational emergency management performance.

Using information: sensemaking and situational awareness

Sensemaking is a core concept in emergency management since the landmark work of Karl Weick on firefighting teams (1993). The idea behind sensemaking is that “reality is an ongoing accomplishment that emerges from efforts to create order and make retrospective sense of what occurs” (Weick, 1993, p. 635). Sensemaking is the continuous process through which people give meaning to the world around them. Failures are bound to happen when sensemaking is distorted and gaps emerge between what people think is going on and what is actually going on. Weick explained the failure of a firefighting team as a collapse of sensemaking process (Weick, 1993). Sensemaking is more than just collecting accurate information about a situation. The sensemaking perspective implies that meaning comes into existence through sensemaking. Sensemaking focuses on action because it is about interpretation. As stated by Weick in later work, "when action is the central focus, interpretation - not action, is the central phenomenon" (2005, p. 409). Sensemaking is a process – the bracketing and labeling of events and deciding upon action – through which tacit knowledge is made explicit and usable. Sensemaking can be an individual and a shared process. At the individual level, sensemaking is a cognitive process concerning the interpretation of information from the senses. At a shared or collective level, sensemaking is distributed over multiple individuals. The main question related to distributed sensemaking is whether shared beliefs, or a shared interpretation, form a necessary condition for organizational or collective action. When information is distributed and interpretations differ, discrepancies and ambiguities can persist (Weick, Sutcliffe, and Obstfeld, 2005). Similar to the role of sensemaking at the individual level, distributed sensemaking is used to explain failures in groups and other collective settings.

A concept that is closely related to sensemaking is situational awareness. Situational awareness was developed as a concept to assess the ability of fighter pilots to keep track of current events and anticipate upcoming events on the battlefield (Sonnenwald & Pierce, 2000). Situational awareness is about extracting information from the environment and using it to have a constantly updated picture of a situation. Situational awareness has been studied both for individuals and groups (Salas, Stout, and Cannon-Bowers, 1994). Situational awareness is very similar to sensemaking as both concepts relate to the processing of information to form an accurate and, in the case of groups, shared understanding of a situation. The difference between the two concepts lies in the idea that situational awareness is about observing a more or less objective environment while sensemaking is explicitly concerned with providing meaning to an environment. What the concepts of sensemaking and situational awareness have in common is their role in the literature on emergency management. Both concepts are perceived as necessary conditions for emergency management to succeed. When the sensemaking process falters, or when actors lack situational awareness, emergency management is expected to be less effective or fail.

Dealing with multiple actors

The emergency management literature has paid ample attention to the role and functioning of inter-organizational networks. Since the response to emergencies nearly always requires the involvement of multiple organizations, coordination between organizations is nearly always a challenge. A lack of coordination between different organizations has often been pointed out as the cause of failure in emergency response (Comfort, 2007). Kouzmin, Jarman, and Rosenthal (1995) and Granot (1997) found that failures of inter-organizational coordination can stem from differences in organizational culture. Research on the improvement of inter-organizational coordination has focused on the role of boundary spanners. As inter-organizational coordination tends to be difficult, certainly in organizational networks that are formed ad hoc under pressing conditions, the explicit appointment of liaisons between organizations has proven to have a positive impact (Kapucu, 2006). Related work has shown that inter-organizational trust has a major impact on the effectiveness of emergency response organizations (Kapucu, 2005). Research on inter-organizational coordination has mainly focused on the tactical and strategic levels of emergency response. Coordination at the operational level seems less problematic and has been characterized as open, constructive and collaborative (Leukfeldt *et al.*, 2007). Despite the fact that operational emergency management is about inter-organizational coordination, the issues and insights studied previously in this body of literature seem to be of little relevance to understand coordination in operational emergency management and the performance of on-scene command teams.

Besides dealing with traditional aspect of emergencies like firefighting and rescuing victims, emergency management is increasingly concerned with the recovery of disrupted infrastructures. An alternative body of literature that helps to understand operational emergency management effectiveness is therefore found in research on infrastructure and reliability management. Research on managing incidents that disrupt complex systems like infrastructures has resulted in the so-called High-Reliability Theory (HRT). This research contains several insights in how effective emergency (or incident) management comes about.

HRT originates from the study of organizations that operate highly complex technologies in which failures can have disastrous consequences. The seemingly 'failure-free' operations of many of these organizations inspired a body of research that tries to explain why these organizations function as reliably as they do. The reliability literature is shaped by a long-standing debate between the advocates of HRT principles and proponents of Normal Accident Theory (NAT). HRT supporters claim that HRT principles make it possible for organizations to prevent failure or, when incidents occur, decline gracefully without disastrous consequences (Rochlin, 1993; LaPorte, 1994; Weick & Sutcliffe, 2007). In contrast, proponents of NAT argue that failure free operation is impossible and accidents are waiting to happen due to complexity, tight-coupling, and necessary compromises with regard to safety (Perrow, 1984). The debate has provided fertile ground for understanding how organizations attempt to operate reliably. High-Reliability Theory is only partially relevant for research on operational emergency management because high-reliability organizations (HROs) operate in settings that are different from emergency management organizations. HROs are traditionally studied as a single organization like an aircraft carrier (Roberts, 1990). An exception is the work of de Bruijne (2006) that focuses on HRT principles in network industries. Moreover, HRT focuses on the workings of entire organizations, not just the role and tasks at the operational level. However, there is one concept from HRT that that relates specifically to the interactions between response actors and coordination at the operational level. This concept is heedful interrelating.

The concept of heedful interrelating has been introduced in the context of high reliability organizations and theories regarding collective mind by Weick & Roberts (1993). Theories of collective mind assume that interactions between individuals create a situation that can be perceived in similar ways as the perception of individual minds. According to this approach, the collective mind – established by a set of individuals – becomes more or less developed depending on the amount and quality of interaction. According to Weick & Roberts (1993), the quality of interaction can vary in terms of heed, in that interaction can be heedful or heedless. However, they do not specify what individual or collective conduct constitutes heedful or heedless interaction, with some exceptions that mainly refer to other ambiguous concepts like constructive interaction (Druskat & Pescosolido, 2002; Eisenberg, 2006). Research on organizational communication is presented as informative in understanding what distinguishes heedful from heedless interrelating (Eisenberg, Goodall Jr, and Trethwey, 2009). However, research on organizational communication does not take into account the specific conditions presented by high reliability environments or crisis management. Heedful interrelating has its roots in the study of well-developed organizations that reliably operate complex systems but Weick & Roberts (1993) state that heedful interrelating also applies to less developed organizations and ad hoc groups. Heedful interrelating might well explain what differentiates effective from less effective emergency response but remains an abstract concept thus far that is difficult to operationalize and observe.

Acting where it matters most

Teams are organizational structures that help to respond quickly to escalating events. This is the dominant perspective on the role of teams in High-Reliability Theory. To manage incidents in complex and tight-coupled systems, strong decentral response capabilities are required. Teams form the most common and suitable platform to mobilize and organize such capabilities. When we use this perspective to study operational emergency management we can state that on-scene command teams contribute to the resilience of society – a complex and sometimes tight-coupled system – since on-scene command teams create an effective organizational structure to deal with emergencies.

Teams have been studied as structures for coordination in HROs (Hofmann, Jacobs, and Landy, 1995). Teams are believed to form adequate organizational structures to coordinate the execution of interdependent tasks. As formulated by Baker, Day, and Salas (2006) “HROs will not achieve high reliability unless its members are able to effectively and efficiently coordinate their activities” (p. 1585). From this perspective, team are assumed to be an essential component of achieving high reliability as they provide an effective platform to coordinate tasks (Baker, Day, and Salas, 2006; Hopkins, 2007). Proponents of Normal Accident Theory agree that teams offer a useful platform for coordination. The presence of such platforms is required in organizations that operate complex technology as they form an arena to facilitate adequate and flexible field-level responses to surprises (Hopkins, 1999;

Smith, 2000). However, NAT continuous by showing that the presence of decentralized decision-making arenas also creates an organizational paradox. Decentralization is needed to cope with complexity while central control is necessary to manage tight-coupled systems (Perrow, 1984). Decentral response capabilities are required to deal quickly with incidents but the autonomy of decentral coordination will inevitably lead to problems in the larger system. Thus, teams are seen as valuable organizational structures by both the proponents of HRT and NAT since teams are structures for coordination that suit the management of complex systems. However, NAT also sees a paradox since decentral arenas cannot be controlled and lack insight in the effects of their decisions in other parts of complex, and tight-coupled systems.

Making the right choices

Emergency decision-making plays an important role in emergency management research. Judgment errors are seen as another reason why emergency response can be ineffective (Kowalski-Trakofler, Vaught, and Scharf, 2003). As described above, insufficient or inaccurate information is perceived as an important reason why emergency responders make the wrong decisions. However, even with sufficient information at their disposal, emergency responders have failed to make the right decisions (Flin, 2001).

Important work on emergency decision-making stems from the naturalistic decision-making (NDM) framework developed by Klein & Zsambok (1997). Naturalistic decision-making has been developed as an alternative to the predominant rationalistic approach to decision-making that is found to be inadequate to explain decision-making under crisis conditions (Flin, 2001). NDM centers around the idea the decision-making is recognition primed rather than a process of judging alternatives. NDM assumes that decision-makers, certainly under pressing conditions, search for patterns in their observations and check whether they recognize a situation from what they have experienced before (Klein, 2008). Naturalistic decision-making was initially developed to explain decisions of individual actors but has been applied to team decision-making as well (McIntyre & Salas, 1995; Lipshitz *et al.*, 2001). Naturalistic decision-making for teams has integrated work on situational awareness and shared mental models. What NDM added to emergency decision-making in teams is a focus on the processes through which decisions are made rather than the content (Lipshitz *et al.*, 2001; McLennan *et al.*, 2006). NDM focuses on the interactions that take place within a team – like adaptability, performance monitoring, and closed-loop communication – and their effects on decision quality rather than the alternatives that are considered and the reasons why alternatives are chosen or not.

Since on-scene command teams make decision under crisis conditions, the insights from NDM research are potentially helpful in understanding their performance. However, NDM research has mainly paid attention to cognitive and behavioral aspects, and left aside the inter-organizational, multi-actor setting in which operational emergency decisions are made. NDM research makes clear that emergency decision-making is an important topic but does not provide a comprehensive framework to understand multi-actor decision-making in operational emergency management.

Collecting, exchanging and processing information are key to coordinating emergency response and therefore emergency management effectiveness. Many factors that have been found to contribute to emergency coordination have something to do with dealing with information. How to organize information exchange is another much used aspect to explain emergency management effectiveness as is emergency decision- making. However, the effectiveness of emergency response cannot only be understood by the activity alone, but also requires that the conditions under which emergency response takes place are taken into account.

2.3.2 Coping with crisis conditions

Operational emergency management is not only defined as an activity itself but also by the conditions under which the activity takes place. Operational emergency management takes place under crisis conditions. These conditions also determine whether and how operational emergency effectiveness comes about. This section introduces crisis management and two concepts that are frequently used to explain crisis management outcomes.

The teams and organizations encountered in the emergency management literature deal with different situations. These situations range from minor incidents to disasters. The situations differ in terms of severity in physical damage and public disturbance (Boin & McConnell, 2007). The literature frequently speaks of incidents, emergencies, and disasters. Incidents are relatively common and only cause a minor distortion of daily routines (Snelder, 2010). Emergencies are larger and less common than incidents. And events that involve substantial damage and create extensive societal disturbance are often referred to as disasters or catastrophes (Boin & McConnell, 2007). The objective size of an event – in terms of damage, victims, and societal disturbance – matters when it comes to categorizing emergencies. However, the severity of damage and public disturbance has a subjective component as well. The subjective experience of societal disruptions influences the (media) attention that is paid to an event, the size of the response organization, and the resources that are made available. Emergencies are also crises.

Crises have been described in terms of their "un-ness" (Rosenthal, Boin, and Comfort, 2001). Crises are unpleasant, uncertain, urgent, unexpected, and unmanageable events. Crises are unpleasant since they involve threat and physical, financial, emotional, and other sorts of damage. Crises are uncertain because both the situation and the way in which the situation must be handled are unknown. Crises are urgent because threat and damage tend to increase without interventions. And crises are unexpected and unmanageable because they are unforeseen and therefore difficult to anticipate (Boin & McConnell, 2007). Another characteristic of crises is the presence of a threat to vital interests. Vital interests are interests that are deemed critical to the functioning of actors involved in a crisis or society at large. The involvement of vital interests adds to the pressure of a crisis situation (Boin *et al.*, 2006).

The question is to what extent we can speak of crisis conditions when it comes to operational emergency management. Emergencies that disrupt infrastructures qualify for most of the characteristics of a crisis. Emergencies are unpleasant, uncertain (although often to a lesser extent than the uncertainty described above), and require an urgent response. Emergencies create damage – both physical and economical - and (local) societal disruptions. Many aspects of an emergency situation are initially unknown, like the cause of an accident, the number of victims, or the presence of life-threatening factors like hazardous materials. A difference between an emergency and a full-blown crisis is the scale of the event. Emergencies are small crises. There are differences between emergencies and crises as well. Emergencies are unpleasant and require an urgent response but they are not unexpected (Perry & Lindell, 2007). Emergencies are uncommon but they are expected to take place every now and then. And although it is difficult to foresee exactly what type of emergencies will occur in the future, it is common practice to prepare in general for events involving considerable damage and societal disruption. This is different for crises that are inherently unexpected and sometimes occur as a mere result of the fact that nobody saw them coming (Quarantelli, 1996; Lagadec, 2005). Besides being smaller and less unexpected than crises, emergencies involve less uncertainty. The uncertainty that is involved in emergencies is primarily the result of incomplete information instead of uncertainty from not knowing how to respond. In sum, emergencies are unpleasant and urgent events, that are expected to happen sometimes and that produce uncertainty mainly as a result of incomplete information. This makes emergencies more manageable than crises. This also makes that lessons from crisis management can be relevant for understanding operational emergency management but the differences between emergencies and crises – primarily the different levels of uncertainty – need to be considered when adopting insights from crisis management to study emergency management.

2.3.3 Coordination versus command and control

Coordination is a core theme in emergency management and crisis management research. On the one hand it is claimed that a clear structure of command and control is necessary for avoiding misunderstandings and confusion of information and overall clarity. On the other hand, it is claimed and often substantiated with empirical evidence that coordinating emergency response involves multi-organizational cooperation that requires emergent coordination (Wimelius & Engberg, 2015). We discuss centralization through three themes: leadership, decision-making and coordination.

Crisis leadership research has focused on the role and effectiveness of leaders during crises. Crisis managers are often high ranking officials that are called upon when crises occur (Smith, 2000). These officials normally perform more routine management tasks within an organization and a body of research has emerged on the qualities of such officials to manage crises (King, 2002; Smith, 2004). A much encountered example of a mistake made by crisis managers is their tendency to get involved with operational issues. Involvement of high-level crisis managers with operational issues is found to have a negative effect on the effectiveness of crisis management (Wooten & James, 2008; Coombs, 2011). Another aspect of crisis leadership is that crises are seen as unique opportunities for leadership and reform. Uncertainty about the appropriate response to a crisis situation is commonly presented as an opportunity for leaders to be influential (Carrel, 2000; Devitt & Borodzicz, 2008). However, Boin & 't Hart (2003) argue that crisis leadership qualities are different from the qualities needed for reform. Researchers have also indicated that situational and organizational control is limited during a crisis and that opportunities to lead are scarce (Pearson & Clair, 1998).

Another central theme in crisis management research is the centralization of decision-making. The so-called centralization thesis holds that decision-making and coordination are centralized in times of crisis ('t Hart, Rosenthal, and Kouzmin, 1993). This is primarily so for strategic decision-making but the same mechanism is observed at lower organizational levels (Stol *et al.*, 2011). The drawbacks of the centralization of decision-making are numerous and have received ample attention. Centralization of decision-making results for instance in information overload at the central decision-making unit, a lack of relevant expertise, and paralysis at lower organizational levels ('t Hart, Rosenthal, and Kouzmin, 1993; Lagadec, 1997; Schwartz & Sulitzeanu-Kenan, 2004). As a result, forms of (unofficial) decentralization are also commonly observed during crises. Due to time pressure and hampered communication, crucial decisions are often made at the operational level of crisis response (Stol *et al.*, 2011). Crises contain opposing forces that provide incentives to centralize as well as to decentralize decision-making. When crisis management is centralized, small groups become the dominant decision structure (Argote, Turner, and Fichman, 1989; 't Hart, Rosenthal, and Kouzmin, 1993). When small groups become the locus of decision-making, group dynamics become an important factor in explaining crisis management effectiveness. This focus has resulted in research on crisis management teams and groupthink (Janis, 1982; Esser, 1998).

The value and feasibility of centralized coordination or command-and-control are widely discussed in the emergency management literature. Command and control structures are efficient and effective in theory but seem to work at least only partially in practice (Groenendaal, Helsloot, and Scholtens, 2013; Boin & Bynander, 2015). Organizing an effective chain of command is especially challenging in the first hours of an emergency. There is often no hierarchy that supports a formal command and control structure since cooperation during emergency response is voluntary by nature and emergency managers only have control over their own organizational resources. Moreover, command and control is difficult to achieve and maintain as commanders or other central decision-making units are able to influence the work of frontline units but cannot effectively control what happens at the frontline (Groenendaal, 2015). Emergent coordination that arises at emergency locations seems more successful in orchestrating emergency response but the factors that differentiate effective from less effective coordination are complex (Groenendaal, Helsloot, and Scholtens, 2013). Another repeated observation is that relatively little coordination in needed as little cooperation takes place in the operational response to emergencies (Berlin & Carlström, 2008). Based on these observations, operational emergency response has been described as 'working together apart' which triggers the question how much coordination is actually needed (Helsloot, 2008).

These insights in crisis management and coordination have value for understanding operational emergency management. On-scene command teams generally do not involve high level decision-makers and leadership of the kind that is thought to be relevant in crises – leadership for reform – is of little relevance for emergency management. However, higher level decision-makers like mayors or local governors sometimes do get involved in operational emergency response. Following the insights from crisis management research, the involvement of decision-makers from the tactical or strategic level of the incident command system can be expected to have negative effect on operational emergency management performance. The discussion on command and control versus coordination is relevant for operational emergency management as well. On-scene command teams can be viewed as a platform for command and control as well as decentralized coordination and decision-making. Looking at operational emergency management alone, on-scene command teams are central decision-making units. When the larger incident command system is considered, on-scene command teams become forms of decentral decision-making. The tension between central and decentral coordination under crisis conditions applies to operational emergency management as well.

A considerable part of emergency management research has focused on how emergency responders deal with the crisis conditions under which emergency response takes place. Not all insights from crisis management research are applicable to operational emergency management but the centralization thesis that returns frequently in the crisis management literature is important for understanding emergency management effectiveness. Emergency response requires immediate, on-scene response as well as an integrated and coordinated response effort. This twofold requirement causes tension in the organization of emergency response. To enable fast local response as well as a larger, integrated response, emergency management is often organized through multiple teams. How teams operate is therefore also crucial to understanding emergency management effectiveness.

2.3.4 Working in teams

On-scene command teams form the core of operational emergency management. Understanding operational emergency management performance is therefore to a large extent about understanding team performance. This section takes a look into the research on teamwork and team performance to understand the factors that drive on-scene command team performance. We start by presenting research on emergency management teams and then proceed to discuss antecedents of team performance in general. We continue with models of team performance and close the section with a presentation of the way performance is conceptualized in team performance research.

Emergency management teams: from road accidents to hurricanes

Emergency management teams are found in many forms (Dunn, Lewandowsky, and Kirsner, 2002). Carver & Turoff (2007) define emergency management teams broadly as "a team of people often representing different organizations, resources and roles" (p. 35). Schaafstal, Johnston, and Oser (2001) in a study on emergency management team training, emphasize the idea that emergency management teams are 'teams of teams' as they generally consist of "multiple teams that come from different organizations, with different organizational goals and different organizational cultures, that work together to minimize the negative effects of the emergency" (p. 615). The notion of emergency management team is used for a variety of teams in different types of settings. What is labeled as an emergency management team in some studies is described as a disaster organization in others. Molino Sr (2006), for example, discusses emergency management teams that deal with common road accidents while Waugh Jr & Streib (2006) use the notion of emergency management team to refer to teams that manage natural disasters. The original nature and task of emergency management teams must be considered before insights from emergency management team research can be used to inform research into on-scene command teams.

What emergency management teams in the literature have in common is that their main task is coordination and decision-making. The conceptual distinction between coordination and decision-making can be fuzzy ('t Hart, Rosenthal, and Kouzmin, 1993; Marks, Mathieu, and Zaccaro, 2001). Decision-making is generally related to processes like collecting information, drafting alternatives, and selecting an alternative (Kerr & Tindale, 2004). Coordination is commonly described in terms of synchronizing actions, like Marks, Mathieu, and Zaccaro (2001) who define coordination as "orchestrating the sequence and timing of interdependent actions" (p. 367). Roughly speaking, decision-making is about deciding what tasks to perform while coordination is related to how tasks are performed (Flin, 2001; Bergström *et al.*, 2010). Research on emergency management teams provides a host of factors that enable coordination and decision-making and through that, emergency management performance. These factors are similar to the drivers of team performance that are found in the more general team performance literature. As a result, we do not discuss the drivers of emergency management team performance separately but discuss them as part of teamwork in general.

Operational emergency management is teamwork

Teams can be conceived of in many different ways and the literature on teamwork and team effectiveness provides a host of explanations for why teams are effective or not (Ledford, Lawler, and Mohrman, 1988; Sundstrom, De Meuse, and Futrell, 1990; Bettenhausen, 1991; Mohrman, Cohen, and Morhman Jr, 1995; Cohen & Bailey, 1997; Devine *et al.*, 1999; Bennett *et al.*, 2003). On-scene command teams are project organizations that exist for as long as an emergency needs to be managed. Their short lifetime and the membership of representatives of autonomous organizations are obvious characteristics that set on-scene command teams apart from more typical types of teams (Cohen & Bailey, 1997). To position on-scene command teams in the wider literature, the literature on team performance is briefly discussed.

Teams are commonly defined as a special type of group (Levi, 2010). So to explicate what constitutes a team, it makes sense to explore what constitutes a group first. There are many explicit and detailed definitions of a group available that bare many similarities and subtle differences (cf. McGrath, 1984; Bettenhausen, 1991; Levi, 2010). There are three main elements that return in nearly all definitions of a group: goal orientation, interdependency, and interaction (Mathieu *et al.*, 2008). Groups have a goal orientation as group members come together for a common purpose. Groups are interdependent. Without the presence of the group, individual group members cannot reach their common purpose so they must come together. And groups involve interaction as team members communicate and interact with each other. So without getting stuck on a specific definition it is possible to state that groups consist of several people that must interact as they are dependent on each other to reach a common purpose.

The distinction between a group and a team is fuzzy but there is a general consensus that "team" is a more inclusive concept than "group" (Levi, 2010). However, there is no consensus on what differentiates a team from a group. Parks & Sanna (1999) show how the concept of a team is generally used to describe groups in work settings. In a similar way, Kozlowski & Bell (2003) place teams in an organizational context as groups that perform organizationally relevant tasks, and thereby exclude social groups. More restrictive definitions can be found as well like the definition of Cohen & Bailey (1997) who built on the work of Hackman (1987) by stating that "a team is a collection of individuals who are interdependent in their tasks, who share responsibility for outcomes, who see themselves and who are seen by others as an intact social entity embedded in one or more larger social systems (for example, […]), and who manage their relationships across organizational boundaries" (p. 241). By referring to interdependence of tasks, this definition of a team goes further than the idea of a common purpose that is used to define groups. Moreover, this definition adds shared responsibility for outcomes and the existence of the team in the perception of internal and external actors. Despite these differences, many studies tend to use the terms group and team interchangeably (Guzzo & Dickson, 1996; Stewart, 2006).

The question is how the characteristics of emergency management teams, and on-scene command teams in particular, relate to the more general conceptualization of groups and teams to understand which insights from team performance research can be used to explain operational emergency management performance. On-scene command teams live up to most of the standards of what constitutes a team. The members of on-scene command teams have a common purpose (besides their individual objectives). They are interdependent, and interact with each other as they cannot reach their objectives on their own. On-scene command teams operate in an organizational context and are perceived as a clear entity, both by the members of the team and by external actors. There are also characteristics that set on-scene command teams apart from the more general team concept. First, a typical aspect of teams that is not satisfied by on-scene command teams is that of shared responsibility. The notion of responsibility in on-scene command teams is complex and will be discussed later when leadership and supervision are discussed. Second, the members of on-scene command teams have clear individual goals within the broader aim of managing the emergency. The distinction between individual and shared goals has received little attention in the team performance literature. And third, although the members of on-scene command teams need to interact to reach their shared goal (and some of their individual objectives); they are also to a large extent independent. For example, firefighting is something that the fire services do without support or consultation of the other emergency services. In sum, on-scene command teams are teams in the common use of the team concept but also have some additional characteristics that have to be taken into account. This means that insights from the broader team literature apply to on-scene command teams but need to be assessed in the light of the specific features of on-scene command teams.

The many antecedents of team performance

Why are some teams more effective than others? This question has inspired a vast body of academic research (Bettenhausen, 1991; Cohen & Bailey, 1997; Cummings & Cross, 2003; Mathieu *et al.*, 2008). In its early stages, team research focused on static antecedents that were hypothesized to affect team performance. This happened in two distinct fields of research (Cohen & Bailey, 1997). Academic research on small group dynamics, mainly rooted in psychology, focused on factors like member identity, conformity, and cohesion to explain group behavior in all sorts of settings. At the same time, more popular management literature adopted teams as a core unit of interest. Research in this area focused on factors like team structure, size and composition, reward structures, and task related technology as predictors of team performance (Bettenhausen, 1991). Early research on team performance accumulated in a body of literature that roughly contains three types of variables; antecedents of team performance (generally studied as independent variables), mediating factors, and team performance measures.

Antecedents · *(mediating factors)* = performance

The quick expansion of potential antecedents of team performance produced a host of difficulties for the accumulation of research findings. Until today, team researchers complain about a lack of clearly defined concepts (LePine *et al.*, 2008; Stewart, 2010). To address these problems, various categorizations of relevant factors in team research have been suggested but no categorization has reached the status of an accepted standard within the academic community (Katzenbach & Smith, 1993; Mohrman, Cohen, and Morhman Jr, 1995; Stewart, 2010). What is available is a broad variety of factors that can help to explain the effectiveness of teams in general (Levi, 2010). A more narrow view has emerged on the factors that mediate team performance. The most commonly included factors are task and environment. A common distinction in relation to team task is made between work, parallel, project, and management teams although various slightly different typologies exist as well (Sundstrom, De Meuse, and Futrell, 1990; Mohrman, Cohen, and Morhman Jr, 1995; Cohen & Bailey, 1997). Environments in which teams operate are described as either stable or dynamic, or certain or uncertain (Day, Gronn, and Salas, 2006; Berg & Holtbrügge, 2010). Various researchers have developed contingency theories that link team characteristics, environmental characteristics and performance (Drazin & Van de Ven, 1985; Cohen & Bailey, 1997). The value of previous research into the antecedents of team performance for understanding the performance of on-scene command teams is limited. Research on antecedents is fragmented and often strongly context dependent. What is important is that these antecedents form a basis for more advanced explanations for team performance that have been developed over time.

Models of team performance: inputs, processes, and outputs

Findings on more or less static antecedents of team performance often raise questions on *how* these factors influence team performance. The effects of static factors like a mixed-age team composition or hierarchical team structure come into being over time. The processes through which this happens make a difference on their own. The performance of teams cannot only be explained with static characteristics of a team but also require insights in the "dynamic, moment-to-moment behaviors and interactions that occur among members while working on the task" (Salas, Burke, and Cannon-Bowers, 2000, p. 341).

Research on the processes through which teams reach performance has produced a variety of models with an input-process-output (I-P-O) structure (Marks, Mathieu, and Zaccaro, 2001; Mathieu *et al.*, 2008).

Input → Processes → Output

In these models, static factors form the inputs for processes that produce outcomes over time. Inputs in I-P-O models are often the antecedents described above. What the I-P-O approach did for understanding team performance is adding a variety of processes that explain how team outcomes come about (LePine *et al.*, 2008). Marks, Mathieu, and Zaccaro (2001) introduced a precise description of team processes as "members' interdependent acts that convert inputs to outcomes through cognitive, verbal, and behavioral activities directed toward organizing taskwork to achieve collective action" (p. 357). This definition distinguishes between taskwork and teamwork. Taskwork refers to the actions a team has to perform to achieve goals and often refer to tasks of individual team members (Salas, Rosen, and King, 2007). Teamwork consists of the processes that are used to "direct, align, and monitor taskwork" (Marks, Mathieu, and Zaccaro, 2001, p. 357). Much studied team processes include planning and dynamic planning (Janicik & Bartel, 2003; Mathieu & Schulze, 2006), shared leadership (Carson, Tesluk, and Marrone, 2007), and task related conflict (Cohen & Bailey, 1997).

Marks, Mathieu, and Zaccaro (2001) have emphasized the importance of the differences between team processes and what they refer to as emergent states. Emergent states concern "properties of the team that are typically dynamic in nature and vary as a function of team context, inputs, processes, and outcomes" (Marks, Mathieu, and Zaccaro, 2001, p. 357). Marks and her colleagues argue that many constructs presented as team processes do actually not refer to interaction processes. As emergent states are often dynamic, they are easily confused with team processes but for explaining team outcomes it makes more sense to treat emergent states as time dependent attributes or traits than actual processes (Kirkman *et al.*, 2004). Research on team processes has increased our understanding of how team performance comes about. Most importantly, it has shown different ways in which team attributes, tasks, contexts, and changes over time add up to team performance. Team processes literature has also been criticized for being unable to adequately accommodate temporal aspects (Gersick, 1988; Stewart, 2006; Carson, Tesluk, and Marrone, 2007). In team process research, longitudinally observed processes are often aggregated into index data to describe one-dimensional links between processes and outcomes without attention to temporal notions. In response to such criticism, team research has evolved towards more advanced models of team performance.

The state-of-the-art: advanced models of team performance

Dissatisfaction with the static nature of much of the team performance research resulted in numerous calls for attention for temporal effects (Worchel, 1994; Cohen & Bailey, 1997). As stated by Mathieu *et al.* (2008), research that investigates teams "on two or three occasions is likely to miss far more of the important dynamics than it is to capture them" (p. 462). Advanced models of team performance accommodate the notion that different processes play a role at different stages of teamwork. To analyze teamwork, dynamic models break the entire team effort down into "more operational and meaningful subperiods" (Mathieu & Schulze, 2006, p. 606). Subperiods are then related to specific team processes that benefit or hamper team performance, during specific stages but in the end also the entire team effort.

Models that divide teamwork on a temporal basis are generally referred to as episodic models (Mathieu & Schulze, 2006).

The most well-known episodic model of teamwork is probably Tuckman's 'forming, storming, norming, and performing' model (Tuckman & Jensen, 1977). However, this model is ill suited to explain performance of teams that exists for a very short time, like on-scene command teams. Another landmark work is the temporally based framework of team performance presented by Marks, Mathieu, and Zaccaro (2001). Marks and her colleagues present an episodic framework of team performance that involves two alternating phases. There are transition phases that refer to "periods of time when teams focus primarily on evaluation and/or planning activities to guide their accomplishment of a team goal or objective" (Marks, Mathieu, and Zaccaro, 2001, p. 360). And there are action phases that concern "periods of time when teams are engaged in acts that contribute directly to goal accomplishment (i.e. taskwork)" (Marks, Mathieu, and Zaccaro, 2001, p. 360). A series of alternating action and transition phases is required for each task that a team does. Action phases are used to execute the actual work while transition phases involve reflection on the accomplished work and planning for a following action phase.

The temporal framework includes a taxonomy of team processes that are central to each phase. For transition phases, team processes involve mission analysis, formulation, and planning, goal specification, and strategy formulation. Central processes for action phases are monitoring progress toward goals, systems monitoring, team monitoring and backup behavior, and coordination. Marks and her colleagues also present three team processes that are relevant for both action and transition phases. These are interpersonal processes of conflict management, motivation and confidence building, and affect management (for an extensive overview and description of the processes see Marks, Mathieu, and Zaccaro, 2001; LePine *et al.*, 2008). By combining the alternating transition and action phases with the taxonomy of team processes, the framework presents teamwork as a series of related I-P-O (Input – Processes – Output) episodes (see figure 2.1) in which "outcomes of initial episodes often become inputs for the next cycle" (Marks, Mathieu, and Zaccaro, 2001, p. 360). The general proposition of the temporal framework of team performance is that the proper execution of relevant team processes during the stages of teamwork "should have a positive influence on team outcomes such as performance and members' satisfaction" (LePine *et al.*, 2008, p. 278).

The temporal framework of team performance assumes that teams perform multiple tasks simultaneously. So instead of one stream as depicted in figure 2.1, teamwork generally consists of multiple parallel streams. The framework also assumes that different tasks demand a different pace of work. These two assumptions combined make that teams are in transaction and action phases at the same time, but with regard to different tasks. Marks and her colleagues acknowledge that it might be difficult in practice to distinguish between different tasks and phases but suggest that thorough task analysis should make it possible to identify both (Marks, Mathieu, and Zaccaro, 2001).

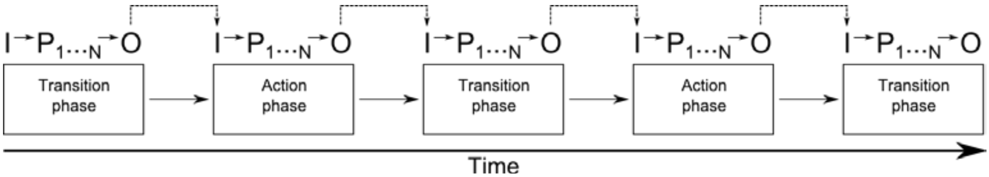


Figure 2.1 - The recurring phase model of team performance by Marks *et al.* (2001)

There is a clear fit between the temporal framework of team performance and the way in which on-scene command teams in the Dutch incident command system work. On-scene command teams meet regularly in team meetings in which the overall emergency response is discussed. The teams than disband to perform specific emergency management tasks in the field. Meetings can be perceived as transition phases while fieldwork constitutes action. The processes used by on-scene command teams are partially different from the taxonomy of processes presented by Marks and her colleagues. To derive at a conceptual framework to understand on-scene command team performance, we have to include different processes. Before turning to these specific emergency management processes, the assessment of performance in the broader team literature is briefly presented.

Conceptualizing team performance: processes, outcomes, and composites

Team performance is often difficult to assess. The question what team performance actually means is frequently addressed in the team performance literature (Mathieu *et al.*, 2008). Team performance is generally presented as a multidimensional concept and most researchers agree that assessing performance on a single dimension is a strong simplification of the multifaceted nature of teamwork. However, the choice for dimensions to assess team performance varies significantly between studies. Piña, Martínez, and Martinez (2008) reviewed the literature and found three common dimensions: performance, attitudinal, and behavioral outcomes (see also: Cohen & Bailey, 1997). Mathieu *et al.* (2008) found a slightly different classification and differentiate between organizational level performance, team performance behaviors and outcomes, and role-based performance (Mathieu *et al.*, 2008). The difference between team behavior and outcomes in this approach is that behavior refers to processes like learning, planning, and cognitive processing while outcomes concern rated performance, either by supervisors, instructors or team members. Although team processes can be included in team performance metrics, it is important to keep a conceptual distinction between process and outcome because "how a team functions (process) is different from what it achieves (results)" (Kaiser, Hogan, and Craig, 2008, p. 98). Consensus has grown that multiple dimensions must be included for a comprehensive assessment of team performance. These so-called *performance composites* "may well be excellent indicators of overall team effectiveness as compared to those that only assess one aspect of performance" (Mathieu *et* *al.*, 2008, p. 417). For a truthful assessment of team performance, we should not only look at the effectiveness with which a team executes its tasks but also at the satisfaction of the team members with the operations of the team.

Team performance can be assessed on various levels of analysis. Common levels of analysis are that of the individual team member, the team as a whole, and the organization of which a team is part (Cohen & Bailey, 1997). What level of analysis is appropriate depends on the context in which a team operates and, obviously, the research question. Assessing performance can be done on the basis of objective measures as well as more subjective measures like supervisor or peer ratings and team surveys (Piña, Martínez, and Martinez, 2008). Objective performance measures are most commonly used to assess task effectiveness of teams with clearly defined tasks. Subjective measures are more often used to assess team member satisfaction and behavioral outcomes and to assess team effectiveness with regard to more complex tasks. Strong performance composites are adjusted to the task a team performs, the characteristics of a team, and the context in which a team operates (Piña, Martínez, and Martinez, 2008). These qualifications provide a basis for the development of a performance measure for on-scene command teams.

Emergency response involves teams and emergency management effectiveness is therefore partially due to team performance. Team research has pointed out many antecedents of team performance and insights have been integrated in the last decade in advanced models that explain team performance as the result of processes over time. These models and insights are relevant for understanding team performance in operational emergency response. Team research has used increasingly complex methods to conceptualize and study team performance, which directs us to the last aspect of operational emergency management to discuss in the context of previous research; operational emergency management performance.

2.3.5 Emergency management effectiveness: we understand failures but not success

The literature on crises and emergencies provides a particular view of how emergency management organizations function. Many dominant insights are derived from case studies with disastrous outcomes; like the Mann Gulch Disaster (Weick, 1993) and the Challenger Launch Decision (Vaughan, 1996). Whereas research on crises and emergencies is intrigued with such situations, there is less attention for the operation of crisis and emergency management organizations that achieve better outcomes. The emergency management literature seems biased towards bad outcomes and generally lacks a systematic approach to understanding emergency management performance.

Studies that explicitly focus on emergency management performance are found in relation to operational teams. In hospital settings, for example, the performance of emergency medicine teams has been studied. Research on emergency medicine teams has assessed team performance on the basis of measurable outcomes and peer judgments

(Shapiro *et al.*, 2004; DeVita *et al.*, 2005). Another frequently studied setting is aviation. Helmreich (2000) studied cockpit crews in operation and used various process indicators like failures of compliance, communication, and procedures to study team performance. These studies use performance composites in that they include both process and outcome indicators but perceive team performance as a single dimension. Aspects of team performance are accumulated in a key indicator that tells whether a team is performing well or not.

The approaches found in the emergency and crisis management literature are of limited value for understanding on-scene command team performance. On-scene command teams operate in complex settings, with multiple actors and multiple objectives. This makes it undesirable to assess performance as a one-dimensional concept. The multi-task, multi-objective nature of emergency management calls for a multi-dimensional perspective on performance. An example of a multi-dimensional measure has been proposed by Schaafstal, Johnston, and Oser (2001) but has not been implemented. Research on operational emergency management has often focused on specific failures while team research has tried to develop a more systematic approach to performance. To accommodate the complexity of emergency management, a multi-dimensional approach to operational emergency management performance will be part of our analytical framework.

2.4 Developing an analytical framework for emergency management performance

The previous sections show how understanding operational emergency management requires insights from different bodies of literature. The aim of this section is to integrate these insights into a comprehensive analytical framework to guide the empirical investigation of this study and to explain variation in operational emergency management performance. The section starts by presenting a structural framework that fits the practice of operational emergency management. We explain as well how structuring coordination in operational emergency management creates a coordination paradox. The section continuous with the presentation of a taxonomy of emergency management processes and an explanation of how these processes enable emergency management performance. As a third step, we show how operational emergency management performance can be assessed in terms of processes and outcomes. The section concludes by presenting our analytical framework.

2.4.1 A recurring phase model of emergency management

There is an obvious similarity between the recurring phase model of team performance presented by Marks, Mathieu, and Zaccaro (2001) and the organization of operational emergency management with support of on-scene command teams. Similar to the recurring phase model, the organization of the response to emergencies is separated in phases of transition (meetings of on-scene command teams) and phases of action (emergency response in the field). The objectives of on-scene command team meetings and emergency response in the field are also similar to processes associated with transition and action phases in the framework of Marks and her colleagues. On-scene command team meetings are about transition processes like reflecting on progress and deciding on subsequent objectives. Emergency response in the field is about the initiation and execution of mono- and multidisciplinary emergency response tasks. The recurring phase model of team performance can be applied to operational emergency response without significant alterations of the model (see figure 2.2). Transition phases are replaced with on-scene command team meetings and actions phases are replaced with emergency response in the field. All other parts of the model remain the same.

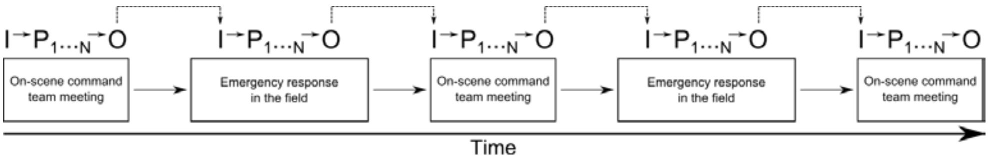


Figure 2.2 - A recurring phase model of operational emergency management

Responding fast and maintaining oversight: a coordination paradox

The centralization paradox encountered in crisis management and normal accident theory describes the tension between a comprehensive, system-wide emergency response and fast response at the operational level. A centralization paradox is also present in operational emergency management. On-scene command teams are a form of centralization in the operational response to emergencies. On-scene command team meetings are used to keep an overview of the situation and the response and to make sure that the emergency response runs as effectively as possible. The actual response takes place in the field by emergency response organizations that individually or collaboratively perform emergency response tasks. The initiation of response tasks in the field needs to be done immediately to create an effective response. The simultaneous need for immediate emergency coordination in the field and oversight and control through on-scene command team meetings forms a tension in operational emergency response.

Emergencies are hectic events and a multi-actor response under hectic conditions requires a clear structure for coordination. As stated by Marcum, Bevc, and Butts (2012) "failure to establish ad hoc control structures under such conditions can lead to conflict between organizations (e.g. due to task interference), failure to complete critical objectives (e.g., due to vital tasks being overlooked or unassigned), inefficiency (e.g. due to repeated performance of the same tasks by multiple actors), or other problems (e.g., underutilization of available personnel)" (p. 519). The organization of operational emergency response generally involves a central structure for coordination. Central meetings make that all actors have the same information, that all actors are involved in the decision-making process, and that all actors are aware of the tasks and objectives of the response organization. In sum, a central sequence of meetings creates the clear structure for coordination and enables the development of an integral emergency response. A centralized coordination structure creates problems as well. Emergencies are complex and dynamic events that involve time-pressure for emergency responders. A central coordination structure is too restricted to accommodate all sorts of coordination that is needed to manage an emergency effectively under such conditions. Task complexity is the reason why the recurring phase model in its original appearance assumes that teams coordinate and perform multiple tasks simultaneously. To perform multiple tasks, several parallel sequences of action and transition phases are required. The rhythm of individual sequences is adjusted to the pace of the specific task around which a sequence evolves. As formulated by Marks, Mathieu, and Zaccaro (2001), the duration of action and transition phases stems from "the nature of the tasks that teams perform and the technology that they employ, and from the manner in which members choose to complete work" (p. 359). The coordination of operational emergency management generally reduces coordination to a single beat of meetings, followed by task execution in the field. While different emergency response tasks have their own rhythm, the alternation of coordination meetings and emergency response in the field takes place at fixed moments. This can be problematic since the reasons to follow the rhythm of a specific task do not disappear. When the rhythm of a task is different from the sequence of meetings, emergency responders face a choice between waiting for the next central meeting to coordinate their next steps or to coordinate in the field. Another issue is that emergency response is a continuous process. Information presented during on-scene command team meetings can become obsolete before a meeting ends. Taking a distance from the field can provide overview but also a lack of relevant, up-to-date information.

Coordination in the field is fast and effective. Emergency responders in the field have the most comprehensive and up-to-date view of the emergency situation and can therefore react immediately and adequately. Coordination in the field fits the needs of specific emergency management tasks – only involving relevant actors – and, as a result, makes the overall emergency response more efficient. Coordination in the field creates significant difficulties as well. Coordination beyond the meetings of on-scene command teams can cause confusion among emergency response actors and thereby slow down the overall emergency response effort. The response becomes fragmented as information is shared between a few actors only and tasks are initiated without informing the entire team. As with centralized coordination, there are advantages and drawbacks to coordination in the field. The strengths and weaknesses of emergency coordination in on-scene command team meetings and emergency coordination in the field are summarized in table 2.1.

	Strengths	Weaknesses
Emergency coordination in on-scene command team meetings	Complete and shared information Integral emergency response	Delays as a result of constrained coordination structure Limited (up to date) information due to 'distance' to the field
Emergency coordination in the field	Fast emergency response Direct access to information	Fragmented emergency response

Table 2.1 - Consequences of centralization for operational emergency management performance

Emergency coordination must take place in the field and in central meetings to develop an integral and fast emergency response. However, upholding multiple places for coordination is likely to result in confusion among emergency response actors. The necessity and difficulty to combine coordination in the field and coordination during central meetings form a coordination paradox in operational emergency management. Emergency response actors have to strike a balance between field coordination and coordination in on-scene command teams to deliver a fast and comprehensive emergency response.

2.4.2 A taxonomy of emergency management processes

Operational emergency management effectiveness depends on the fast and adequate initiation of emergency response tasks in the field and the development of an integral emergency response through operational coordination. Actors and teams that initiate emergency tasks quickly and effectively and orchestrate the response in an efficient manner will, in the end, achieve more results than actors and teams that are biding or unable to develop an efficient response strategy. Our recurring phase model of operational emergency response (see 2.3.1) depicts how emergency response is structured in a sequence of performance episodes; emergency response in the field and on-scene command team meetings. Similar to the taxonomy of processes in the framework of Marks and her colleagues, we identify emergency management processes that enable the execution and coordination of emergency response tasks in on-scene command team meetings and during emergency response in the field. The processes are derived from the different bodies of literature discussed in section 2.3. The emergency management processes that enable emergency response in the field are situational awareness and emergent coordination. Processes that enable the coordination of emergency response during on-scene command team meetings are collective sensemaking and emergency decision-making. These processes are selected because they fit practice of operational emergency response. The other emergency management processes discussed are discarded as they are less suitable to operational response. This section first describes the four selected emergency management processes as enablers of operational emergency management performance and subsequently discusses why other processes are discarded.

Situational awareness: developing and maintaining the operational picture

Situational awareness is about the development and maintenance of an operational picture, an adequate understanding of the existing situation (Sonnenwald & Pierce, 2000). The gathering and integration of situational information is a fundamental aspect of emergency management as information is a crucial resource. The importance of information is reflected by the emphasis that is placed in emergency management research on concepts like sensemaking and situational awareness. These concepts focus on how actors obtain, share, and interpret information and how failures to do so result in problems in emergency response. Actors cannot respond effectively to an emergency without an accurate understanding of the situation. However, the need for information goes beyond the collection of information about the emergency situation alone. Actors must also find out what other actors know and what emergency response efforts are being made. Such a situational assessment can only be made when sufficient information is available. The need for information does not diminish after the initial drafting of an operational picture. Actors need to maintain their situational awareness continuously to understand how the emergency situation and the emergency response are developing. To maintain situational awareness, actors involved in emergency management have a permanent need for information regarding the event itself and the response organization. To perform well – with regard to monodisciplinary as well as multidisciplinary tasks – actors need to collect and verify information continuously and maintain their situational awareness.

Emergent coordination: organizing the response on the spot

Emergent coordination refers to the organizing of emergency response tasks in the field. Emergent coordination is required when several emergency response actors have to collaborate to perform a multidisciplinary task or when multiple emergency response actors have to orchestrate their actions as a result of interdependencies. Emergent coordination in the field is the counterpart of comprehensive coordination that takes place in on-scene command team meetings. Emergent coordination involves similar coordination processes like situational assessment, deciding on goals and a course of action, division of tasks, and the orchestration of the concurrent execution of multiple tasks.

Emergent coordination enables an effective emergency response as it accelerates the initiation and execution of emergency response tasks. As explained above, coordination in on-scene command team meetings can have a delaying effect on emergency response and response in the field is often faster. Response in the field can also be more efficient as it only involves relevant actors instead of all actors that are present in on-scene command team meetings. Emergent coordination is required to initiate and execute emergency response tasks in the field and is therefore an enabler of effective emergency response.

Collective sensemaking: jointly determining what's going on and what to do

Collective sensemaking is about joint interpretation and acting upon shared information (Thomas, Clark, and Gioia, 1993). Information is often spread over different emergency response actors that gather information in the field. The first part of collective sensemaking is therefore about the sharing and verification of dispersed information to a form a common operational picture. The second part is the development of shared understanding – shared situational awareness – on basis of the common operational picture. Shared understanding implies that the meaning of information – for example the priorities in an emergency situation – is shared between different actors. Collective sensemaking is a continuous process, just like situational awareness. Not only because emergency situations change continuously, but also because sensemaking includes acting upon the current understanding of the situation. Acting upon the shared understanding of the situation and testing the accuracy of the common operational picture by verifying whether chosen actions have the expected and desired effect is part of collective sensemaking as well.

Collective sensemaking is crucial to effective emergency response as it helps to avoid misunderstandings between different emergency response actors. The primary reason why on-scene command teams exist is that they help to develop an integral emergency response. Given the hectic and uncertain conditions of an emergency, on-scene command teams have the challenge to create oversight, decide upon an effective response strategy and the prioritization of response tasks, and the coordinated execution of the emergency response. This requires a process of collective sensemaking through the development of a common operational picture and a shared situational understanding of an emergency situation.

Emergency decision-making: selecting a course of action

Emergency decision-making is about goal setting, deciding on a course of action, and the allocation of resources. There is overlap between emergency decision-making, emergent coordination, and collective sensemaking. Emergent coordination is also about deciding on a course of action and the allocation of resources and collective sensemaking is about goal setting as well. The reason why emergency decision-making is presented as a separate process is that it is more explicit process, primarily visible when it comes to crucial decisions in an emergency response. Emergent coordination is often implicitly done with regard to specific tasks in emergency response and collective sensemaking is about the integration of different tasks in a comprehensive emergency response. Emergency decision-making becomes a prominent process when crucial response tasks require influential decisions under considerable uncertainty. As described in section 2.3.1, emergency decision-making is often not a rational process of selecting the most suitable alternative from a variety of options but more about acting upon recognition of previously encountered situations – so-called naturalistic decision-making. The role of supervisors or team leaders is also important because these actors often have considerable influence on the decision-making process or the decision itself (Day, Gronn, and Salas, 2006; Zaccaro, Heinen, and Shuffler, 2009).

Emergency decision-making is a key enabler of an effective emergency response as the outcomes of decisions often have considerable effects on the course of an emergency response. Taking risks under uncertain conditions can have particularly successful as well as disastrous effects. Risk aversion or non-decision-making, on the other hand, can also have significant positive as well as negative effects in emergency situations. Emergency decision-making is a key process in emergency management as crucial decisions have the ability to make and break the effectiveness of emergency response.

Why we do not include plans or leadership

The four processes described above – situational awareness, emergent coordination, collective sensemaking, and emergency decision-making – are selected as key enablers of emergency management effectiveness in our analytical framework. The four processes are selected because they are most suitable to explain performance in the setting of operational emergency management and on-scene command teams. We explain briefly why other processes have been discarded.

Emergency response planning is a common factor in emergency management research and emergency response plans have been presented as enablers of emergency management effectiveness (Perry & Lindell, 2007; Kapucu, 2008). We choose to leave emergency planning out of our analytical framework because research has shown that planning is of limited relevance at the operational level. A gap has been observed between emergency response planning and practice, especially at the operational level. van Zanten & Helsloot (2007) have argued that the crisis and emergency response system consists of two sub-systems. A formal planning arena on the one hand in which policies are developed (mainly in response to recent incidents) and a practical arena in which emergency services practice and prepare for coming events on the other. Where the planning arena relies on formal plans to structure emergency response, the practical arena relies mainly on improvisation and common sense (Scholtens, 2009). Emergency response plans are more or less irrelevant at the operational level of emergency management. Moreover, the formal cycle of emergency planning, evaluation, and adjustment of emergency response plans is mainly focused on the strategic or policy level and much less on the operational level of response (van Zanten & Helsloot, 2007; Jong, 2009; Scholtens, 2009). In sum, emergency response planning is of little relevance for the practice of operational emergency management.

A second possible factor for explaining emergency management effectiveness is leadership (Waugh Jr & Streib, 2006; Devitt & Borodzicz, 2008). Leadership has received ample attention in research on crisis management and the management of emergencies and natural disasters. Leadership is discarded in this study for two reasons. First, the scale of the emergencies studied is relatively small, providing little opportunity for the type of leadership that is commonly studied in crisis management research. Uncertainty and societal disruptions are often limited, and leadership in operational emergency management is rather practical instead of inspirational. Second, the practical role of supervision and leaders of on-scene command teams is part of collective sensemaking and emergency decision-making and is therefore already adopted in the framework.

Another common factor for explaining emergency management performance, particularly in relation to emergency response teams, are skills, knowledge, and attitudes (so-called KSAs) (Salas, Burke, and Cannon-Bowers, 2000; Salas, Rosen, and King, 2007). The ability to execute emergency response tasks relies upon the skills and knowledge of emergency response actors and the ability to coordinate the response is partially dependent upon the attitudes of actors involved. The primary reason to leave these factors out of our analytical framework is that the emergency response actors in our study possess more or less the same skill and knowledge levels. All officers that take part in operational emergency management have received the same basic education and training. So where skills and knowledge can help to explain the overall quality of emergency management, there is little variation in skill and knowledge levels that can help to explain variations in emergency management outcomes. The attitudes of emergency response actors might vary and therefore explain why emergency coordination succeeds or fails. Attitudes are left out of the analytical framework because we are interested in how emergency management performance comes about as a result of emergency management processes and attitudes are an input for the such processes rather than a process in itself. How attitudes influence emergency management processes remains an interesting issue that is not an independent part of the framework but returns in the study of each emergency management process.

2.4.3 A multifaceted view on emergency management performance

The objective of operational emergency management is to execute emergency response tasks and to coordinate the operational response to emergencies. Our analytical framework is developed to explain how operational emergency management performance comes about (or not). This section describes how we depict operational emergency management as a multifaceted concept that includes multilevel task performance and emergency response actor satisfaction.

Tasks and outcomes

In line with recent insights in team performance research, we aim to develop a performance composite to assess operational emergency management performance in terms of outcomes and processes. The emphasis is placed on outcomes since we are primarily interested in the degree in which different emergency management objectives are achieved. Since operational emergency management does not only involve a team effort but also the achievement of individual emergency response actors, the research focuses on different levels at which performance can be assessed.

Outcome performance of operational emergency management turns around the question whether the right tasks have been executed in the right way or order. High outcome performance means that operational emergency management is effective and efficient – many emergency response tasks are performed in little time. Operational emergency management performance is multilevel performance. The most elementary level is that of individual emergency response tasks. It is possible to check for each relevant task whether and when it has been initiated, executed, and successfully finished. The second level is that of individual emergency response actors. Actors are responsible for multiple tasks, both monodisciplinary and multidisciplinary. To assess actor performance it is necessary to accumulate the performance of the different emergency response tasks in which an actor is involved. The third level is that of the entire operational emergency response organization or the on-scene command team. On-scene command teams are responsible for all emergency response tasks. Assessing on-scene command team performance therefore necessitates the accumulation of performance of all emergency response tasks that are relevant in the response to an emergency. The three levels of operational emergency management performance are shown in figure 2.3.

Processes and actor

Since this research is aimed at the effectiveness of different aspects of emergency management, outcome assessment forms the primary indicator of performance. However, focusing on outcomes alone without paying attention to the processes through which outcomes are achieved provides a narrow view of operational emergency management performance. It is therefore desirable to include aspects of the emergency response process in the performance assessment as well. There are few formal criteria to assess the processes in operational emergency response. There are no formal templates for the collection of information, decision-making, or the handling of differences of opinion. Ideally, on-scene command teams must always reach consensus and agree on a response strategy.

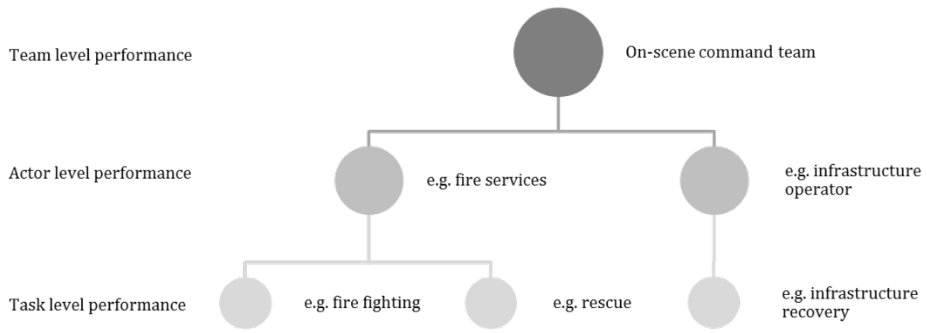


Figure 2.3 - Multilevel emergency management task performance

The lack of formal templates for operational emergency management processes makes it difficult to assess process performance systematically. It is therefore necessary to adopt an open and inductive approach to assess the extent in which emergency response actors are satisfied with the response. As a result of how emergency management processes have evolved, actors can feel involved in the emergency management process or feel neglected or rejected. This aspect of operational emergency management (process) performance can be assessed through the subjective experience of the actors involved. Their satisfaction with the emergency management processes is part of operational emergency management performance as well.

2.4.4 The analytical framework

The previous sections describe how operational emergency management consists of two alternating phases, what emergency management processes determine operational emergency management performance, and how we conceive of emergency management performance. We conclude this section by integrating these pieces into an analytical framework for our research. Our analytical framework of operational emergency management is shown in figure 2.4. The framework consists of two alternating phases: emergency response in the field and emergency response during on-scene command team meetings. The outputs of the previous phase form the inputs of the subsequent phase. Each phase holds two emergency management processes from our taxonomy. Situational awareness and emergent coordination are key to effective emergency response in the field. Collective sensemaking and emergency decision-making enable effective emergency response in on-scene command team meetings. Operational emergency management performance consists of task performance and process performance.

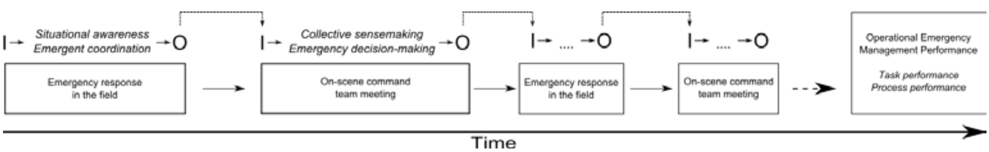


Figure 2.4 - Our analytical framework for operational emergency management performance

2.5 The analytical framework and emergency management in the Netherlands

Operational coordination of emergency response is done by on-scene command teams *(in Dutch: Commando Plaats Incident (CoPI))* in the Dutch incident command system. The Dutch incident command system is partially regulated by law through the Safety Regions

Act (2010) and partially by informal guidelines. To understand how our analytical framework relates to the practice of operational emergency management in the Netherlands we describe the Dutch incident command system. We subsequently discuss how our recurring phase model and taxonomy of emergency management processes are linked to the Dutch situation and how on-scene command teams coordinate emergency response.

The three-tier structure of the Dutch Incident Command System

The Dutch incident command system has a three-tier coordination structure: strategic, tactical, and operational (Brainich von Brainich Felth, 2009; Scholtens, 2009). The composition of the core coordinating team for each tier is shown in table 2.2.

Tier	Team	Team composition
Strategic level	Regional policy team (RBT)	Chairman Safety Region Public prosecutor Chairman Water Board (Further similar as Municipal policy team)
	Municipal policy team (GBT)	Mayor Director Public Health Director Medical Emergency Services Director Fire Services Director Police Communications officer
Tactical level	Regional operational team (ROT)	Operational leader Senior fire services officer Senior police officer Senior medical emergency services officer Senior public health officer Communications officer Information manager
Operational level	On-scene command team (CoPI)	Team leader Fire services officer Police officer Medical emergency services officer Public health officer Information manager Press officer

Table 2.2 – Organizational structure of the Dutch incident command system

Mayors are the principal decision-makers during emergencies and lead the coordination at the strategic and highest tier. In case of large-scale emergencies, mayors assemble a team of advisors, a municipal or regional policy team, to decide on strategic issues (Jong, 2009). When an emergency takes place within the boundaries of a single municipality, a municipal policy team (*Gemeentelijk Beleidsteam - GBT*) is formed. When an emergency affects multiple municipalities, the mayors involved join each other in a regional policy team (*Regionaal Beleidsteam - RBT*) that is headed by the chairman of the local Safety Region. Policy teams consist of the directors of all emergency services. At the second, tactical tier, a regional operational team (*Regionaal Operationeel Team - ROT*) is formed to support the response at emergency locations and to take care of the effect area when an emergency has significant disruptive effects on its surroundings. Operational teams set up a communication action center to inform the public about an emergency, arrange emergency logistics and manage the area that is affected by an emergency. Operational teams are composed of representatives of the emergency services and a representative of the local municipality. An operational team is headed by an operational leader - a commanding chief of one of the emergency services (Jong, 2009). The terminology of the Dutch incident command system can be confusing as operational teams actually do not act at the operational but at the tactical level. Operational emergency management is organized at a third and operational tier. Operational coordination takes place in on-scene command teams that are formed at emergency locations. On-scene command teams coordinate the operations of all emergency and other services at an incident site. On-scene command teams inform the regional operational team and policy teams about the emergency situation.

Escalation levels

The size and structure of the organization that is put into operation in response to an emergency in the Netherlands is predetermined by the GRIP framework *(*in Dutch: *Gecoördineerde Regionale Incidentbestrijdings Procedure)*. The GRIP framework relates the scope and intensity of an emergency to four escalation levels (see table 2.3).

Escalation level	**Scope of an emergency**	**Incident command system response**
Escalation level 1 (GRIP 1)	Incident area	On-scene command team (CoPI)
Escalation level 2 (GRIP 2)	Incident area and effect area	On-scene command team (CoPI) + Regional operational team (ROT)
Escalation level 3 (GRIP 3)	Threat to the well-being of the local population	On-scene command team (CoPI) + Regional operational team (ROT) + Municipal policy team (GBT)
Escalation level 4 (GRIP 4)	Threat to the well-being of the population beyond the local municipality	On-scene command team (CoPI) + Regional operational team (ROT) + Regional policy team (RBT)

Table 2.3 - Escalation levels in the Dutch incident command system

The first and lowest escalation level – GRIP 1 – is used in response to large-scale but locally contained emergencies that require coordination between multiple emergency services. The organizational structure of GRIP 1 consists of an on-scene command team alone. The second escalation level – GRIP 2 – is announced when local emergencies have a considerable disruptive effect on their surroundings. In case of GRIP 2, an on-scene command team coordinates the response at an emergency location while an operational team organizes the response for the area that is affected by an emergency. GRIP 3 – the third escalation level – is activated when a significant part of a local or regional population is threatened. In this situation, a municipal policy team is assembled to organize the care for the local population. The organizational structure of the highest escalation level – GRIP 4 – involves a regional policy team, municipal policy teams that deal with strategic issues in the municipalities involved, an operational team that deals with tactical issues and potentially multiple on-scene command teams to coordinate the operational response. GRIP 4 is announced when the effects of an emergency reach beyond the borders of a single municipality (Brainich von Brainich Felth, 2009; NIFV, 2012). The escalation level that is used in response to an emergency can be determined by mayors, the leader of an operational team, the leader of an on-scene command team, and each officer from the emergency services, preferable in consultation with other members of the on-scene command team (Jong, 2009). The GRIP framework is no formal regulation but adhered to by all Dutch Safety Regions (Brainich von Brainich Felth, 2009).

GRIP 1: operational emergency management

This research concentrates on emergencies with a disruptive effect on infrastructures. Such emergencies are managed at the lowest, operational level of the incident command system where on-scene command teams are the common platform for coordination. When emergencies are small, emergency services can also coordinate their collaborative efforts informally in field-meetings (so-called hood-meetings because they take place around the hood of an emergency response vehicle; in Dutch: *motorkapoverleg)*. This is done when the management of an emergency requires some coordination at the emergency scene but the officers involved see no need for a formal escalation level and the formation of an on-scene command team. The decision to coordinate the response in field-meetings or to announce a GRIP 1 situation and form an on-scene command team is not made on the basis of fixed criteria but based on the subjective decisions of one or more of the officers involved. The decision to call for a higher escalation level can be made by each officer in the operational emergency response. When the disruptive effects of an emergency are not limited to an emergency location but also involve the surroundings of an emergency, a GRIP 2 response including a regional operational team can be announced.

In practice, the operational management of emergencies with a disruptive effect on infrastructures will vary between field-meetings, and a GRIP 1 or GRIP 2 escalation level, depending on the situation and the decisions of the emergency officers involved. The disruption of infrastructures is no immediate cause for a GRIP 2 situation as the effect area is different from the local surroundings of an emergency. To deal with the disruptive effect on the infrastructure, a liaison from the infrastructure operator is often added to the on-scene command team. The most common organizational structure in response to emergencies that disrupt infrastructures is GRIP 1, where a representative from the disrupted infrastructure system is added to the on-scene command team.

On-scene command teams: multidisciplinary, public-private, ad-hoc project organizations

On-scene command teams in the Dutch incident command system routinely involve officers from the traditional emergency services (fire services, medical emergency services, and police), a representative from the municipality in which the emergency takes place, a press officer (police), an information manager, and a team leader. The involvement of these core emergency response actors in on-scene command teams is laid down in formal guidelines for the incident command system (NIFV, 2012). Besides the core actors, representatives of organizations that are accidentally involved in an emergency situation – like utility companies or infrastructure operators – can be added to an on-scene command team (Leukfeldt *et al.*, 2007). This is also the case for advisors on specific issues like hazardous materials or environmental care. There is no formal arrangement to decide when and whether external representatives become part of an on-scene command team or not. In practice it is the team leader that decides to invite a representative, preferably in consultation with other members of the team. Together, the representatives form a project organization for the duration of the response to an emergency and disentangle once the emergency is over or when the situation is controlled to the extent that the need for operational coordination has disappeared. An on-scene command team is best described as a project organization since the members represent autonomous agencies that temporarily join forces to manage an emergency situation.

Supervision in on-scene command teams

On-scene command teams are headed by a team leader, a senior officer of the fire services and representative of the Safety Region. As a team leader, the officer no longer acts as a representative of the fire services but as a generic emergency manager. The formal position of the team leader is that of a *primes inter pares,* a first amongst equals. The team leader chairs on-scene command team meetings but is not officially ranked above the other officers in the team (VRR, 2008; VRZ, 2011b). There is little formal guidance on how decisions within on-scene command teams should be made but the basic idea is that consensus among emergency response actors must be reached (Leukfeldt *et al.*, 2007). There is no formal basis for strong or decisive leadership by team leaders. Mayors are formally responsible for the entire emergency response organization (Brainich von Brainich Felth, 2009). This is one of the reasons why team leaders often stay in touch with mayors during an emergency response. In case of crucial decisions, team leaders can contact the mayor who has formal authority. The hierarchy in the Dutch incident command organization and in on-scene command teams is relatively weak as it consists of formally independent actors that coordinate the response on basis of equality.

Multidisciplinary coordination by on-scene command teams

The nature of emergency management as a multi-task, multi-objective activity is reflected in the overview of emergency response tasks that is used by the Dutch Safety Regions and laid down in emergency management guidelines (VRR, 2008; VRZ, 2011b). These guidelines specify a variety of tasks that are either the responsibility of a specific emergency service (monodisciplinary tasks) or the joint responsibility of multiple emergency services (multidisciplinary tasks)(Leukfeldt *et al.*, 2007). Containing hazardous materials or treating wounded victims at the emergency site are examples of monodisciplinary tasks that belong respectively to the fire services and the medical emergency services. Victims rescue and traffic management, on the other hand, are usually a joint task of multiple disciplines. Victims rescue is done by the fire services and medical emergency services together and traffic management is a shared task of the police and infrastructure operators. Coordination of emergency response tasks takes place in the field and in on-scene command team meetings.

The initiation and execution of emergency response tasks takes place in the field. Monodisciplinary tasks can often be initiated right away after emergency responders have explored the emergency situation and become situationally aware. Multidisciplinary tasks that need to be performed by multiple emergency services and monodisciplinary tasks that are somehow related to other tasks require coordination from the start. Emergent coordination in the field is necessary to initiate multidisciplinary and interdependent response tasks. On-scene command team meetings provide a single sequence of moments at which all relevant emergency response actors come together and discuss the emergency response. This reduces the rhythm of teamwork – the parallel rhythms presented by Marks and her colleagues –to a single beat. On-scene command teams engage in collective sensemaking an emergency decision-making to be able to coordinate response tasks effectively. These processes can be explained through the elements of the ‘BOB’ model, a model that is commonly used to structure on-scene command team meetings.

The BOB model stands for ‘Beeldvorming’ which means creating a shared understanding of the emergency situation, ‘Oordeelsvorming’ – the performance of a shared situational assessment, and ‘Besluitvorming’ – emergency decision-making. Creating a shared understanding of an emergency situation is a core emergency management process. An assumption of the BOB model is that shared understanding of the emergency situation is a prerequisite for effective coordination. A shared situational assessment is required to develop an integral emergency response. The emergency services need to reach consensus on what tasks need to be executed and in what order. This is particularly difficult when emergency situations are uncertain because uncertain conditions introduce risk assessment to a situational assessment. The final step of the BOB model consists of emergency decision-making. A team needs to prioritize response tasks and decide what resources are allocated to what tasks. Decision-making is about what to do, when to do it, and who should be doing it. A final task of on-scene command teams that is not covered by the BOB model is to inform higher level actors in the incident command system. In practice, this means that the leader of an on-scene command team informs the mayor and the leader of the regional operational team on a regular basis (Bharosa, Appelman, and de Bruin, 2007).

In sum, operational emergency management in the Dutch incident command system is about the execution and coordination of mono- and multidisciplinary emergency response tasks. The operational emergency management organization and on-scene command teams are composed of a diverse group of actors that together form a project organization for the duration of the emergency. Supervision is arranged through the presence of a team leader that leads team meetings but is formally equal to other emergency response actors. Coordination of emergency response tasks emerges in the field and is formally structured in on-scene command teams that are used to create shared situational understanding, perform situational assessments, and engage in emergency decision-making.

2.6 Conclusion

This chapter described the important factors in the process of emergency response that determine emergency management performance, and explained how these factors can be combined into an analytical research framework.

The important factors in the process of emergency response that determine emergency management performance are found in different bodies of research. Emergency management research has focused on the exchange of information and decision-making during emergency response and provides several concepts like situational awareness, sensemaking, and emergency decision-making to explain emergency management effectiveness. Operational emergency management cannot merely be defined as an activity in itself since the crisis conditions under which it takes place must be considered as well to understand how operational emergency management effectiveness comes about. Crisis management research has frequently focused on how emergency responders deal with crisis conditions. This research points at the importance of organizing an immediate local response as well as an integrated and coordinated response effort. The tension that comes with this double requirement is a central aspect for understanding emergency management effectiveness. Emergency response is organized through teams and understanding team performance is therefore key to understanding emergency management performance. Team research provides several models of team performance that are relevant for understanding team performance in operational emergency response. Research on operational emergency management has generally focused on specific cases involving failing emergency response organizations. Team research has developed more systematic approaches to address and assess performance. We use the insights from team research to develop a more systematic approach for understanding emergency management performance.

The insights from different bodies of research are integrated into an analytical research framework The analytical research framework consists of two alternating phases: emergency response in the field and emergency response during on-scene command team meetings. The outputs of a preceding phase form the inputs for a subsequent phase. We define emergency management processes that determine emergency management performance for each phase. Situational awareness and emergent coordination are presented as key to effective emergency response in the field. Collective sensemaking and emergency decision-making enable effective emergency response in on-scene command team meetings. The analytical research framework guides our empirical investigations to explain variation in operational emergency management performance.

Chapter 3
Virtual reality exercises

3.1 Introduction

Virtual reality technology has been widely adopted by the emergency services for training purposes and exercises. This chapter describes virtual reality exercises, explains why they provide an opportunity for research, and introduces the virtual reality exercise scenarios that form the basis of this study. The key question in this chapter is how the important factors in the process of emergency response and emergency management performance can be studied during virtual reality exercises.

We start by explaining why virtual reality exercises provide an opportunity for research, especially for studying multidisciplinary coordination and infrastructure recovery (section 3.2). Section 3.3 discusses virtual reality exercises in general. The virtual reality exercises that are organized by Safety Region *Zeeland* and that form the research setting for this study are presented in section 3.4. We proceed by introducing the four virtual reality exercise scenarios in section 3.5 in which we describe the narrative of each scenario, the actors that take part in the exercises, and analyze the challenges that each actor faced. A conclusion is provided in section 3.6.

3.2 An opportunity for research

We use virtual reality exercises to study operational emergency management. We explain why virtual reality exercises are chosen as a research setting by addressing two questions. First, what are the characteristics of virtual reality exercises that make them an attractive and useful setting for studying operational emergency response? And second, why are virtual reality exercises particularly apt to study multidisciplinary coordination and infrastructure recovery?

Using virtual reality technology for emergency management research

Research on emergency management is hampered by difficulties of getting access to emergency situations and the fact that emergencies are rare and unique events that are difficult to compare and study systematically. The literature on emergency management includes different research approaches. Case studies are common in emergency management research (Lalonde, 2007). The strength of case studies is that they provide a complete and in-depth account of emergency management in practice. However, case studies are often difficult to perform due limited access to real-world emergencies, and only give insight in unique events which frustrates comparative research (Granot, 1997; Roux-

Dufort, 2007). To solve the access problem, emergency management research is often based on simulated emergencies and emergency exercises. Simulated emergencies make it easier and safer to collect information, perform direct observation, and simulate situations that are impossible to study in real life.

A significant part of emergency management research is based on studies that take place in simulated settings. Part of these studies involve large-scale simulation exercises that are organized only once (Borodzicz & van Haperen, 2002; Boin, Kofman-Bos, and Overdijk, 2004; Borodzicz, 2004; Strohschneider & Gerdes, 2004; Helsloot, 2005; Bergström *et al.*, 2010). These large scale emergency simulations require physical areas to be fenced of and facilities to close down. To limit these disruptive effects, emergency simulations are organized and repeated with a low frequency. Using such simulations for research solves the access-problem but not the problem of a lack of comparable cases. Thus far, emergency management research rarely involves the systematic, comparative analysis of emergency response under similar conditions.

The use of virtual technology is extending the possibilities to do research (Cohen *et al.*, 2013). Virtual reality exercises can realistically simulate dangerous situations without putting the participants at risk. Virtual reality exercises are more realistic than the maquette exercises they usually replace (Harteveld & De Bruijne, 2009; Harteveld, 2012). And in contrast to on-site exercises, virtual reality exercises can be organized without disrupting real-world facilities. The rise of virtual reality exercises provides emergency management research with an opportunity to obtain comparable cases. As stated by Meijer (2009), simulation gaming has the potential to create useful settings for 'controlled analysis' as simulation games can simultaneously provide realism to participants and control to researchers. Virtual reality exercises are increasingly used for research in emergency management (Louka & Balducelli, 2001; van Ruijven, 2011). An important quality of virtual reality exercises is that the realism of the virtual environment in combination with the authentic simulation of the response organization present a transactional whole of emergency response (Shank, 2013). The idea of a transactional whole is discussed in the next chapter. For now it is important to stress that a transactional whole is a setting that contains all interactions between actors and actors, and actors and objects, that occur in reality. The use of virtual reality technology helps to include more items from reality than maquette exercises. The interactions between actors and actors are already authentically simulated in maquette exercises. The detail and realism of virtual reality environments makes it possible to simulate objects in detail and to simulate the interaction between actors and objects.

Virtual reality technology has already been used to study several aspects of emergency management. The triage of victims has been studied by Andreatta *et al.* (2010) and Vincent *et al.* (2008), among others. Decision-making by incident response commanders has been studied by Lamb *et al.* (2014). And virtual reality technology has been used in emergency medicine to study and improve surgery (Seymour *et al.*, 2002) and team skills (Bradley, 2006).

There are limitations to the use of virtual environments for emergency management research as well. There are differences between real emergencies and simulated emergencies in virtual settings. Virtual reality exercises do not include the physical conditions of a real emergency nor can they depict every detail that is present in a real emergency. Simulations might not be able to produce the same levels of stress and confusion that are experienced during a real crisis situation ('t Hart, 1997). These differences raise the question whether emergency responders act the same during virtual reality exercises as they do during real emergencies. This question cannot be answered without comparative research between emergency response in real and simulated setting. Such a comparison is not made in this study but the possible differences between real and virtual settings are considered when the implications of the research are discussed. The fact that the two settings are different makes that we must be careful in transferring the outcomes of research in virtual reality exercises to the real-world. However, virtual reality exercises do contain all elementary aspects of emergency response, both objects and actors. As explained before, virtual reality exercises provide a transactional whole of emergency management. The transactions might be different – shorter, longer, less stressful – but the combination of transactions is similar. This makes real-life emergencies and virtual emergencies comparable, at least at a conceptual level. This implies that it is possible to draw inferences from simulations if one carefully considers the differences with the real world (Helsloot, 2005; Moats, Chermack, and Dooley, 2008).

Virtual reality technology offers an opportunity to study operational emergency management because it allows for direct observation of emergency responders in action and the repetition of identical scenarios. These characteristics make that virtual reality exercises are an attractive setting for studying operational emergency management, despite the differences between real-world and simulated emergencies.

Observing multidisciplinary coordination

To facilitate research on operational emergency management in a multi-actor setting, virtual reality exercises must focus on multidisciplinary coordination. The need for multidisciplinary coordination varies between emergency situations. Emergencies happen in relative isolation as well as in dense urban or industrial areas. Emergencies take place in public areas and in privately owned facilities. Depending on the scenario and location of an emergency, more or less emergency response actors are involved, and more or less multidisciplinary coordination is needed.

Multidisciplinary coordination is required when emergency response involves multiple actors and when these actors have shared tasks or when they have to cooperate to fulfil individual tasks. Emergencies that take place in relative isolation, for example forest fires, are sometimes managed by the fire services alone. Emergencies that take place in facilities like industrial plants, airports, or other large facilities are sometimes managed by the facility operators alone. In these cases, emergency response is a mono-actor activity that does not require multidisciplinary coordination. Public emergency services will only get involved in these situations when the emergency runs out of control. Most emergencies, however, involve multiple actors. Common road accidents, for example, require the involvement of at least the traditional emergency services: the fire services, police, and medical emergency services. Emergencies with a disruptive effect on their environment require involvement of other actors like municipal representatives, infrastructure operators, or advisors on hazardous materials. The mere involvement of multiple actors does not lead to multidisciplinary coordination per se. The actors need to be dependent on each other to necessitate coordination. Some emergency response tasks are taken care of by emergency services alone. Firefighting is done by the fire services, the provision of medical care is done by the medical emergency services, and criminal and forensic research is a task of the police. Emergency response actors only need to coordinate with regard to these tasks when the tasks are somehow dependent upon other tasks. Other tasks, like evacuation or the recovery of disrupted infrastructures, is a shared responsibility of multiple actors.

The more interdependent and multidisciplinary tasks need to be performed in response to an emergency, the larger the need for multidisciplinary coordination. Virtual reality exercise scenarios can be designed without the limitations of a physical environment or real-world setting. This makes them apt to develop scenarios with many interdependent and multidisciplinary tasks and thereby create conditions that require multidisciplinary coordination.

Studying infrastructure recovery

Virtual reality technology is particularly useful for the simulation of physical objects. This makes virtual reality exercises especially useful to study the recovery of physical infrastructures that are disrupted as a result of incidents. This also means that virtual reality exercises are not suitable to study the recovery of all types of infrastructure. The growing importance of infrastructure reliability for the well-being of society is one of the motivations for this study. The importance of infrastructures is reflected by the label 'critical' that is assigned by policy makers to infrastructures that are essential for the functioning of a society and economy. Providing the label critical to infrastructures is an international development reflected in policy programs of the United States (Lewis, 2006) and the European Union and its member states (Baker, Day, and Salas, 2006). In the Netherlands, a selection of critical infrastructures ('*vitale infrastructuur*') has first been made in 2002 (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2002). In 2013, 12 sectors were relabeled as critical, jointly including 31 critical goods or services, see table 3.1.

Energy: electricity, natural gas and oil;
Telecommunications and ICT: land-line and mobile telephony, radio, broadcasting and the internet;
Drinking water: the water supply;
Food: the food supply (including in supermarkets) and food safety;
Health: emergency and hospital care, medicines, vaccines;
Financial sector: payments and money transfers by public bodies;
Surface water management: water quality and quantity (control and management);
public order and safety;
Legal order: the courts and prisons; law enforcement;
Public administration: diplomacy, public information, the armed forces, decision-making;
Transport: Amsterdam Schiphol Airport, the port of Rotterdam, highways, waterways, railways;
The chemical and nuclear industries: the transport, storage, production and processing of materials

Table 3.1 - Critical infrastructures ***(Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013)***

The selection of critical infrastructures is broad and diverse. Critical infrastructures have in common that their functioning is essential to the well-being of society but beyond that they differ in many respects. Some infrastructures involve physical systems while others, like public administration or the legal order, consist of organizational and institutional arrangements. Some infrastructures, like hospital care and chemical industry, are geographically bounded while others, like the electricity grid and telecommunications, span large geographic areas. And more variation can be found, like the type of organization that operates an infrastructure (e.g. public, private, or both) or the connectedness of infrastructures with other infrastructures (isolated or closely intertwined). Because of the specific capabilities of virtual reality environments, physical infrastructures like chemical plants, transport networks, or energy systems are most likely to play a role in virtual reality exercises. Simulation of the financial sector, the legal order, or public administration requires artificial intelligence rather than virtual reality. Operational emergency management is also primarily relevant in relation to physical infrastructures. Whereas infrastructure recovery is the direct result of emergency management in physical infrastructure, recovery of non-physical infrastructures requires other processes that are closer to business continuity management. The scope of this research is therefore limited to physical infrastructures.

Virtual reality technology is well suited to simulate different physical infrastructure systems. The technology is able to simulate disruptions that occur as a result of incidents in a realistic way. Virtual technology is thereby capable of taking dependencies between infrastructures into account. When other infrastructures depend upon the functioning of a disrupted infrastructure, the cascading effects for related infrastructures can be simulated as well (Nieuwenhuijs, Luiijf, and Klaver, 2009). Virtual environments are well-suited to simulate physical environments like one or multiple large-scale physical infrastructures and their dependencies. Virtual reality exercises are therefore particularly suitable to study the response to emergencies that take place in the context of such physical systems and that are likely to have a disruptive effect on the system in which they take place.

Adding a methodological component to the study

The primary aim of this study is to gain insight in operational emergency management in a multi-actor, multi-objective setting. The choice of virtual reality exercises as a research setting adds a methodological component to the study. Studying emergency response in virtual reality exercises requires methods and tools that suit the specific characteristics of the setting. The proximity of the researcher to the emergency responders in action, and the fact that the entire exercise takes place on a single location creates new opportunities for research and observation. Virtual reality exercises are relatively new and it has not been tested yet what research methods can be applied, and with what outcome. While focusing on operational emergency management, this study also provides an application and test of a combination of a new research setting with new research methods.

Chapter four presents the research design of this study. The design includes communication network analysis and video-observation for the analysis of emergency response processes and a task score method for the assessment of operational emergency management performance. The methods are chosen and combined to increase the rigor of the analysis and to study operational emergency management in a systemic way. The search for useful and valid methods to analyze player behavior is one of the current challenges of serious gaming (Harteveld, 2012). Gaming technology makes it possible to track player behavior and to generate large amounts of behavioral data. The use of virtual technology is creating the possibility to track behavior as well during emergency management exercises. The use of network analysis for the analysis of player behavior is not new to serious gaming research (Chen, Huang, and Lei, 2006; Suznjevic, Dobrijevic, and Matijasevic, 2009). However, these studies concerned large data sets from Massive Online Multiplayer Games and focused on the behavior and performance of individual players only. Little attention has been paid thus far for performance and behavior at the organizational or team level. Because the test of methods is not the primary aim of the research, there is no formal evaluative framework to test the quality and applicability of the methods employed. However, the usefulness of the methods to gain insight in operational emergency management, and the limitations of the methods will be discussed in the final chapter.

The standing practice for the evaluation and assessment of virtual reality exercises is observation. Virtual reality exercises are managed by an exercise staff. The exercise staff acts as a response cell during the exercises and provides counter play to the participants. After the exercise, the exercise staff discusses and evaluates the mono- and multidisciplinary performance of the participants. The feedback is based on observations made during the exercise. Advantages of observation are flexibility, sensitivity to context and conditions, and the expertise of the observers who can interpret actions and situations as they enfold. Disadvantages are its limited capacity (observers can focus on one actor or situation at a time), observation is difficult to perform systematically, and the possible occurrence of observer bias (e.g. individual interests or emphasis on the last thing observed)(DeWalt & DeWalt, 2010). The drawbacks of observation as the only input for evaluation form a motivation to explore methods to assess and analyze virtual reality exercises with more systematic methods. The next chapter presents performance assessment and communication network analysis as two methods that are used to study operational emergency management. We will return to the observation and evaluation of virtual reality exercises in practice in the final chapter and reflect on the potential value of the research methods employed in this study for the evaluation of virtual reality exercises in practice.

3.3 The virtualization of emergency management exercises

Virtual reality exercises are becoming a standard component of the preparation of emergency management. Virtual technology is providing more and more ways to simulate emergencies, to train emergency responders, and to practice and prepare safely and systematically for dangerous and complex emergency situations. Since virtual reality exercises are central to this study, we shortly explain what virtual reality exercises are and how emergency services use them to increase their preparedness for emergency situations.

Virtual reality technology

Education, training, and exercises used for the preparation of emergency management are becoming increasingly digitalized and virtualized. The use of virtual reality technology is gradually becoming common practice, especially in the preparation for operational emergency management. In line with the development of virtual reality technology in the simulation and gaming industry, virtual reality environments for training purposes have been developed since the early 1990's. As one of the first, ETC (Environmental Tectonics Corporation) developed ADMS (the Advanced Disaster Management Simulator), a simulation environment that was first used in 1992. The main purpose of ADMS was to support training exercises with realistic visualizations and to present situations that are difficult or impossible to simulate in reality (Louka & Balducelli, 2001). In the Netherlands, comparable systems have been developed by E-semble (XVR™) and VSTEP (RescueSim™). What these systems have in common is that they offer a three-dimensional virtual reality environment, presenting authentic or imaginary locations, in which emergency scenarios can be simulated and acted upon. Because most virtual reality environments are based on technology adopted from the commercial gaming industry, the use of these environments is commonly referred to as serious gaming.

Virtual reality technology is particularly suitable to simulate physical and technological environments. Virtual environments for emergency management exercises commonly involve infrastructural and industrial facilities like road networks, ports, railroads, industrial facilities and urban environments (McGrath & McGrath, 2005; Cohen *et al.*, 2013). The environments are apt to simulate emergencies like fires, floods, or chemical spills. The simulation of victims is also a popular application of virtual environments because the modelling of victims, including a variety of injuries, fits well in the possibilities of virtual technology (Rutschmann *et al.*, 2006; Jarvis & de Freitas, 2009; Heinrichs *et al.*, 2010). Non-physical infrastructures and security threats are more difficult to represent with virtual technology. Artificial intelligence and complex systems simulations become increasingly advanced and features like crowd simulation have been integrated with virtual technology (Dignum *et al.*, 2010; Lukosch, van Ruijven, and Verbraeck, 2012). Despite these technological developments, virtual emergency exercises tend to stick to the basic virtualization of environments and remain under control of exercise facilitators and instructors who control the events and role-play human behavior.

Narratives, players, and challenges

Virtual reality exercises are frequently referred to as serious games because of the use of gaming technology. However, virtual reality exercises are difficult to fit into the broader field of serious gaming. To explain the nature of virtual reality exercises, we describe them in terms of serious games, simulations, and training exercises.

Serious gaming research is a young field of scholarly research in which terminology can be confusing. Besides serious gaming, terms like gaming simulation, simulation games, and applied games are used, often interchangeably. Providing a single definition for serious games is difficult and does not reflect the broad variety of applications of gaming technology and principles – either digital or analogue – to create societal, economic or political value (Mayer, Warmelink, and Zhou, 2015). Providing a broad definition that covers all thinkable serious games is not helpful in explaining what virtual reality exercises are and how they relate to other types of serious games. A more useful approach to characterize virtual reality exercises in relation to serious games is provided by Costikyan (2013) who argues that serious games are characterized by the presence of game mechanisms like roles, rules, competition, scores, and luck (Costikyan, 2013). Actors that engage in games take up a role and their interaction is structured by rules. The goal of games is often to win and movement towards goals is tracked trough progress points or scores. Additionally, luck often plays a role in games. Virtual reality exercises make use of some of these mechanisms. Roles are defined by the real life occupations of participants and the exercises have little rules of themselves but interaction is shaped by the formal and informal rules of the real-world institutional context of emergency management. There is no luck or competition in virtual reality exercises and progress nor outcomes are tracked with support of scores. Using Costikyans' perspective, virtual reality exercises possess only some characteristics of serious games.

Serious games often involve a model of the real world, a simulation on basis of which the game takes place. When this is the case, serious games are also referred to as gaming simulation, simulation games or simply simulations. Simulations involve a model of reality that can be used to study, predict, and experiment with the system on which the model is based (Duke, 1980; Meijer, 2009). Simulations can exist independently as formal models without human participation but games require the participation of players. Simulation games and gaming simulation refer to combinations of a simulation – a model of a system – with characteristics of gaming – the involvement of autonomous players. Simulation gaming is described by Geurts and Duke (2004) as "an operating model of a real-life system in which actors in roles partially recreate the behavior of the system" (p. 37). Virtual reality exercises involve a simulated environment, often visually detailed but without any interactive systems modelling. To describe virtual reality exercises as simulation games does therefore put too much emphasis on the simulation part.

The primary aim of virtual reality exercises is to train emergency responders. Virtual reality exercises can therefore also be viewed as training exercises that make use of virtual technology to increase the realism of the exercise. Much research on emergency management training exercises and the use of virtual technology has been conducted at the institute for simulation and training of the University of Central Florida. This work shows that virtual and simulation-based training contributes to team performance (Rosen *et al.*, 2008; Salas *et al.*, 2008; Weaver *et al.*, 2010). Most research has been done in healthcare settings and on the performance of medical teams. The inter-organizational, multi-actor setting of emergency management has not been studied thus far.

Virtual emergency management exercises do not match with a single existing concept but contain different aspects of serious games, simulations and training exercises. In terms of serious games, virtual reality exercises can maybe best be described as what Salen & Zimmerman (2004) describe as games as systems of information. Players (emergency response actors) start with imperfect information on which they must act. Throughout the exercise, the players gain more information until they finish in a state of perfect information but no more chances to act. Because of the absence of game mechanisms and the limited role of simulation, the use of virtual environments for emergency management exercises will – in line with Harteveld (2012) – be referred to as virtual reality exercises and not as simulation games or serious games.

Besides the question whether virtual reality exercises as a phenomenon in itself can be defined as serious games, the question can be asked whether the participants of virtual reality exercises engage in 'gaming' or 'play'. This question can be answered by considering the extent to which the participation in virtual reality exercises conforms to what Salen & Zimmerman (2004) have defined as meaningful play. Meaningful play "emerges from the relationship between player action and system outcome; it is the process by which a player takes action within the designed system of a game and the system responds to the action. The meaning of an action in a game resides in the relationship between action and outcome" (Salen & Zimmerman, 2004, p. 34). Playing a game involves making choices. The meaning of choices is defined by the game-system and the context in which the game is played. The choices of players and the resulting actions change the game-system and thereby produce meaningful outcomes. Meaningful play – the process of making choices and changing the game system – enables experimentation and experiencing that results in learning (Salen & Zimmerman, 2005). The participants of virtual reality exercises make choices that result in changes of the virtual reality exercise system. The decision of the fire services, for example, to fence of an emergency site because of the threat of an explosion, changes the exercise and determines the remaining choices of the fire services and other actors involved in the exercise. The choices of participants in virtual reality exercises have meaning, both in the exercise as in the real world. Participation in a virtual reality exercise can therefore be seen as a form of meaningful play.

The perception of virtual reality exercises as meaningful play is enabled by three characteristics of virtual reality exercises: narrative, players, and challenges. The narrative is found in the emergency scenarios that enfold during the exercises. The players are the emergency response actors that take part in the exercises. The challenges are the tasks that emergency response actors have to take care of and the decisions they have to make. The combination of narrative, players, and challenges, makes virtual reality exercises a form of meaningful play from which emergency response actors learn and in which they simulate the response to emergencies as if they are acting in a real-life situation.

3.4 Virtual reality exercises in Safety Region Zeeland

We studied operational emergency management in a series of virtual reality exercises organized by Safety Region *Zeeland*. This section addresses how Safety Region *Zeeland* uses virtual reality exercises and describes the organization of the virtual reality exercises that are used in this study.

Multidisciplinary virtual reality exercises with infrastructure operators

This research has been conducted at Safety Region *Zeeland*. The province of *Zeeland* is situated in the south-west of the Netherlands and is characterized by an abundance of waterways. The region includes landmark infrastructures like the *Oosterscheldekering*, the *Zeeuwsch-Vlaamse Kanaalzone*, and the *Westerschelde Tunnel*. The region also includes important facilities like the ports and industry of *Vlissingen* and *Terneuzen*, the nuclear power plant of *Borssele*, and a number of canals and sluices that connect the main river deltas with ports and the hinterland.

Safety Region *Zeeland* has adopted virtual reality exercises as a standard practice in the preparation and training of emergency services. Safety Region *Zeeland* uses virtual environments for monodisciplinary training of individual emergency responders (*bevelvoerderstrainingen*) as well as multidisciplinary exercises for on-scene command teams (*CoPI oefeningen*). Safety Region *Zeeland* expressed the intention of becoming a continuous learning organization in its policy plan for 2012 – 2015 (VRZ, 2011a). As part of the efforts to reach this objective, the Safety Region organizes a continuous program of multidisciplinary exercises. One sequence of these exercises is organized on-site, the other sequence consists of virtual reality exercises. The sequence of virtual reality exercises is organized with a high frequency to provide an opportunity to all officers from all emergency disciplines in the region to take part in an exercise at least once a year. Exercise scenarios are developed and repeated for at least half a year until most officers have taken part in the scenario. The repetitive use of exercise scenarios by Safety Region *Zeeland* provides an opportunity for the comparative study of operational emergency management. The virtual reality exercises at Safety Region *Zeeland* do also provide an appropriate setting because they are focused on operational response, multidisciplinary coordination, and explicitly include the disruption of infrastructures.

Starting in the spring of 2011, Safety Region *Zeeland* organized a sequence of exercises involving the *Westerschelde Tunnel* and the main waterway '*Kanaal door Walcheren*'. The exercises involved a custom made virtual environment of the *Westerschelde Tunnel* and a general urban environment that served as the cities of *Middelburg* and *Veere*. For the exercises that involve the *Westerschelde Tunnel*, employees from the *Westerschelde Tunnel* operator were invited. For the exercises involving the waterway, the waterway operator '*Rijkswaterstaat*' was role-played by the exercise staff.

Virtual reality exercises at Borssele fire station

The exercises were organized at the fire station of the fire services at *Borssele*. The *Borssele* fire department is especially equipped and situated to respond to emergencies at the *Westerschelde Tunnel*. The fire station has two dedicated education and training rooms. The presence of the two adjacent rooms makes the fire station well-suited for virtual reality exercises. In one room, the virtual environment is setup for the situational assessment and performance of monodisciplinary tasks. This room represents the 'field'. In the other room, the meetings of the on-scene command team are held. This room represents the on-scene command team meeting facility and is referred to as the meeting room. The 'field' room has four positions with a large monitor showing the virtual environment. These positions consist of a projection screen, a beamer, a joystick, and a satellite laptop that runs the virtual environment. The positions are occupied by the main emergency response actors. Besides the actor positions, a central spot in the 'field' room is reserved for the technical facilitator. This position consists of a desk and a server laptop from which the virtual environment is managed. The on-scene command team meeting room is divided in two areas. One area is used for the on-scene command team to use for their meetings. The meeting area consists of a table with as many seats as there are members in the on-scene command team, a projection screen, a beamer, and a laptop that is used by the information manager.

The observation area is used by the exercise staff and others to observe the exercise. Figure 3.1 shows a map of the two at *Borssele* fire station. The virtual environment that is used by Safety Region *Zeeland* for virtual reality exercises is provided by E-Semble. E-Semble is a provider of simulation software for emergency services and industry. The virtual environment used consists of the XVR™ virtual reality training software. The version of XVR™ used by Safety Region *Zeeland* at the time of the exercises was based on the

Quest3D™ game engine[4]. The exercises that involved the *Westerschelde Tunnel* were based on an authentic three dimensional model of the *Westerschelde Tunnel* that has been developed for the *Westerschelde Tunnel* operator and the Safety Region *Zeeland*. For the emergency scenarios involving the *Kanaal door Walcheren* a fictional setting including a canal, port, and urban environment was used. Figures 3.2 – 3.5 provide an impression of the exercises.

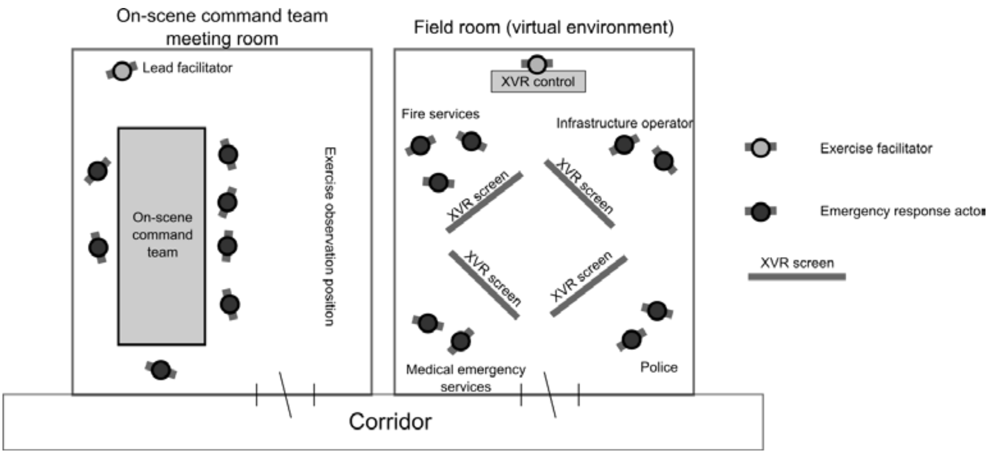


Figure 3.1 – Virtual reality exercise setting

[4] At the time of the research, E-Semble was redeveloping the XVR virtual reality training software by making a transition from Quest3D™ to the Unity™ game engine. The transfer did not affect the research as the implementation of the new software at Safety Region *Zeeland* took place after the research was finished.

Figure 3.2 - Two police officers in front of the virtual reality environment of the Westerschelde Tunnel

Figure 3.3 – An on-scene command team leader explains the emergency situation to his team

Figure 3.4 - Commanders from different disciplines take part in a field meeting

Figure 3.5 - An on-scene command team leader prepares for a team meeting

Exercise staff, participants, and schedule

Virtual reality exercises are managed by a team of facilitators that is headed by a lead facilitator. The lead facilitator acts as a host during the exercises, briefs the team of facilitators, and keeps the overview during the exercises. The lead facilitator is supported by the technical facilitator who manages the virtual environment. The technical facilitator creates and loads an exercise scenario in the virtual environment, makes adjustments in the environment when the exercise proceeds or if requested by a participant, and responds to technical when these are encountered during an exercise. Besides the lead facilitator and the technical facilitator, the team of facilitators consists of members from the emergency response disciplines involved in an exercise. Often, the participants of a morning exercise acted as facilitators in an afternoon exercise, and vice versa. Where the lead facilitator is concerned with the multidisciplinary part of the exercise, his team of facilitators deals with monodisciplinary aspects and provides counter play to the individual disciplines. To coordinate the facilitation of the exercise, the team of facilitators is briefed before the exercise starts and receives a copy of the detailed scenario, usually a few days before an exercise takes place.

The participants of virtual reality exercises come from all departments within the Safety Region *Zeeland*. This means that some participants are more familiar with the situation and location encountered in the exercise scenario than others. The participants are generally only distantly acquainted with each other. This resembles the way in which on-scene command teams are formed in reality. In case of a large-scale emergency, an on-scene command team is formed with the officers that are on duty at that specific moment. The formation of on-scene command teams for the exercises is therefore comparable to the formation of teams in practice. The participants of virtual reality exercises included a fixed core and a group of non-standard participants that only participated when the exercise scenario offered them a substantial role. The fixed core consisted of officers (*Officieren van Dienst*) from the traditional emergency services – the police, fire, and medical emergency services –, the municipality, a team leader (*Hoofd Officier van Dienst*) and an information manager.

Two exercises are organized on a single day, one in the morning and one in the afternoon. As many of the participants join both in the morning and in the afternoon session (with different roles, either as participant or facilitator), a day includes two different exercise scenarios. The exercises start with a briefing of the facilitating team. The facilitators receive information about the scenario and the goals of the exercise. After the briefing of the facilitating team, the participants of the exercise are gathered to get their briefing. When playing the scenario involving the *Westerschelde Tunnel*, the briefing contained a short reminder of specific instructions for the tunnel and the emergency response procedures. The briefings of the facilitating team and participants combined takes up around thirty minutes. After the briefings, the exercises start with the spread of initial information on the incident. The participants then leave the meeting room to go to the 'field' room to head for the emergency location and do their first situational assessment. After an exercise finishes, the participants split up for a monodisciplinary evaluation. These take approximately twenty minutes. After the monodisciplinary evaluation, the participants regroup for a multidisciplinary evaluation that takes approximately thirty minutes.

We were allowed to observe all virtual reality exercises between the spring of 2011 to the end of 2013. Video-recording was allowed as long as all participants agreed (which they did without exception). The Safety Region allowed us to hand out questionnaires after each exercise and to talk with participants and staff during and between the exercises. The only restrictions that were made concerned the study and reporting of the introduction and use of information management. The role of the information manager and a new information management system was introduced in the spring of 2011. As the introduction of information management was expected to go through some difficulties during the start-up, the Safety Region asked us not to evaluate or focus on this aspect.

3.5 Four virtual reality exercise scenarios

The virtual reality exercises studied involve four emergency scenarios. All scenarios were repeated multiple times with different participants. The emergency scenarios share many characteristics. All four scenarios involved the three traditional emergency services (Fire Services, Medical Emergency Services, and the Police). The scenarios present an emergency of a scale that requires a response of at least GRIP 1. And the scenarios involve a disruption of a critical infrastructure. Beyond these shared characteristics, the scenarios involve different storylines, a different emergency response organization, and a different emergency response. The emergency scenarios involve the disruption of two different infrastructures. Two scenarios revolved around emergencies in the *Westerschelde Tunnel* (WST). The other two scenarios concern a disruption of main waterways. The scenarios involving the *Westerschelde Tunnel* both relate to large road accidents. One involves hazardous materials and the other a touringcar with many passengers, creating the need for a large-scale evacuation. The scenarios in which main waterways are disrupted involve hazardous materials in an urban environment and a large-scale carbon monoxide leakage in a port. The scenarios and actors involved in each scenario are listed in table 3.2.

Scenarios	**No. of exercises**	**Emergency response actors involved**
Westerschelde Tunnel hazardous materials scenario	6	Fire services, Medical emergency services, police, municipality, on-scene command team leader, information manager, tunnel guard, tunnel emergency coordinator, advisor on hazardous materials, press officer, fire service commander, mayor(s), second police officer.
Westerschelde Tunnel evacuation scenario	4	Fire services, Medical emergency services, police, municipality, on-scene command team leader, information manager, tunnel guard, tunnel emergency coordinator, advisor on hazardous materials, fire service commander, second police officer(s), and touringcar operator.
Urban hazardous materials scenario	6	Fire services, Medical emergency services, police, municipality, on-scene command team leader, information manager, fire service commander, shipping company liaison, mayor.
Port carbon monoxide scenario	4	Fire services, Medical emergency services, police, municipality, on-scene command team leader, information manager, sailing school manager, KNRM liaison, fire service commander, waterway liaison.

Table 3.2 - Virtual reality exercise scenarios

Each exercise scenario is described and analyzed. For each exercise, the main storyline of the scenario is presented, followed by an analysis of the actors involved, and the challenges the actors face in the form of emergency response tasks involved, the timeline and interdependencies of tasks, and a presentation of the assessment of emergency management performance in the specific scenario.

3.5.1 The *Westerschelde Tunnel* hazardous materials scenario

The narrative: a collision and hazardous materials leakage in the Westerschelde Tunnel

"A multi-vehicle collision has occurred in the eastern tunnel of the Westerschelde Tunnel, near cross-passage six. A tank truck is involved as well as multiple cars or vans. An unknown number of people are injured and some people are supposedly trapped in their car following the collision. The tank truck is leaking, its contents are unknown…"

This message is transmitted by the emergency dispatch center to all emergency responders as they drive towards the Westerschelde Tunnel. The message stems from the tunnel operator who has seen the accident via the tunnel video monitoring system. The tunnel operator has immediately activated the alarm system in the coordination center. The alarm system causes both tunnels to close for incoming traffic and opens the cross-passages between the tunnels to allow people to escape from one tunnel to the other. The alarm system shifts the direction of the ventilation system[5] and alarms the tunnel guard to go to the non-accident tunnel for further inspection. The alarm system automatically informs the fire services.

In case of an alarm from the Westerschelde Tunnel, fast response units from the fire services in Terneuzen and Borssele go to the emergency scene. The units from Terneuzen approach the tunnel from the south and the units from Borssele come from the north. The fast response units are soon followed by a pre-set selection of fire engines. The police and medical emergency services are alarmed by the emergency dispatch center. According to the Westerschelde Tunnel emergency response plan, they drive towards deployment positions at the tunnel entrances. The police and medical emergency services are not allowed to enter the tunnel as long as the fire services have not declared the situation to be safe. The municipality is informed as well and the municipal officer on duty is send to the tunnel.

Heavy traffic - The accident causes a stir in the region. When the Westerschelde Tunnel closes, all road traffic between the southern and northern parts of Zeeland – and the

[5] The ventilation systems is reversed to prevent smoke or gas from entering the non-accident tunnel right when it is blown from the accident tunnel.

important industrial areas of Vlissingen and Terneuzen – has to take a detour that takes at least an hour and often more. Right after the closure of the tunnel, traffic at the northern and southern entrances of the tunnel is chaotic. A traffic jam starts to form at the toll stations. Cars that already entered the access roads to the tunnel have to wait for the emergency barriers. Due to the heavy traffic, the roads that the emergency response units need to use to reach the tunnel are threatened to be congested.

The municipality and the operator of the Westerschelde Tunnel are contacted immediately by the local industry and media for further information. The press wants to know about the severity of the accident and industry is interested in the duration of the tunnel closure. These questions, however, cannot be answered as long as adequate information about the situation is lacking.

Chemicals - The fire service officer is the first officer to arrive at the emergency scene. He enters the non-accident tunnel and awaits a report from the commander of one of the fast intervention units that have driven into the accident tunnel. After a first inspection, the commander tells the officer that the tunnel is completely blocked, that eight cars seem to be involved in the accident, and that eight persons are found with injuries. One of the victims is trapped inside a vehicle. The scale of the emergency is considerable and the tunnel will be blocked for at least several hours. For how long exactly is difficult to say. The fire services declare the situation in the non-accident tunnel safe, which means that the other emergency services can enter the non-accident tunnel.

Considering the size of the accident, it is likely that one of the responding officers has called for a GRIP 1 response already. If this is not the case, the emergency dispatch center calls for a GRIP 1 at this point. A leading officer – the HOVD – is alarmed and an on-scene command team (CoPI) is formed. A special container unit is brought into the non-accident tunnel to facilitate meetings of the on-scene command team. When the fire services explore the accident scene further, they find that the tank truck is leaking gasoline. The car in which an person is trapped is standing right next to the leakage and rescuing this person becomes a priority. At the same time, the fire services discover that one of the vans that are involved in the collision contains a barrel with a chemical substance. The barrel is damaged due to the collision and can start leaking at any moment. Its contents are thus far unknown.

Evacuating victims - People involved in the collision suffer from various injuries. Some are severely wounded and need medical care on the spot. The number of victim presents a challenge to the medical emergency services that have to arrange adequate care at the emergency scene. Victims that only suffer from minor injuries are treated by the medical emergency responders. Some severely wounded victims are treated and transported to local hospitals. The medical emergency officer must decide how many ambulances to order and whether to ask for a mobile medical team (MMT) to treat severely wounded victims at the accident scene. If asked for, the MMT will come by helicopter from Rotterdam. Besides the persons involved in the accident, a group of people gathers in the non-accident tunnel. They come from cars that got stuck behind the accident. The people have left the accident tunnel through the cross-passages. These people need to be evacuated as well. A shelter location is arranged by the municipal officer who is taking care of the non-injured people involved. The municipality can use a nearby facility, the "Dow farm" as a shelter location. The farm is situated near the southern tunnel entrance and is available. The farm is large enough to accommodate a large group of people. The municipality is also arranging buses to bring non-injured people from the accident scene to the shelter location.

More heavy traffic - Traffic remains chaotic at both sides of the tunnel. Ambulances that are heading for the tunnel threaten to get stuck. The medical emergency services ask for assistance from the police to reach the tunnel quickly. The tunnel operator has automatically activated a detour for the main traffic routes when activating the emergency alarm. The situation at the toll stations remains hectic and the police send additional surveillance units to manage traffic at the tunnel entrances. The police also find out that the driver of the van that contains a barrel with a chemical substance is a known criminal suspect. He has been arrested in the past for the illegal dumping of chemicals. The police want to arrest the driver and send a surveillance unit. The fire services try to figure out what is in the barrel to determine whether the emergency services can do their work safely.

Clearing and cleaning the emergency site - When most people are evacuated from the tunnel, the fire services officer hears from his commander that the fire services have control over the situation. The leakage has stopped and the substance that has leaked from the tank truck is contained in one of the tunnel's reservoirs. The barrel in the van turns out to contain a non-dangerous and non-toxic material. In the meantime, the person that was trapped has been rescued and the driver of the van has been arrested by the police. The medical services are bringing the last victims to local hospitals. It is now safe for all emergency services to do their work in the accident tunnel. The police start the forensic investigation to determine the causes of the accident. The tunnel operator inspects the accident scene to see what materials are required to remove the damaged vehicles and to assess the possible damage that has been done to the tunnel. The damage is limited but special salvage material is needed to remove the tank truck. The mayors of Terneuzen and Borssele contact each other and, in consultation with the Westerschelde Tunnel operator, decide that the tunnel must be reopened as quickly as possible. They want to limit the hindrance for the region. Forensic research, if possible, must happen at a later stage with support of pictures and video-images.

The players: actors in the Westerschelde Tunnel hazardous materials scenario

Virtual reality exercises involve a selection of core actors and, depending on the exercise scenario, a selection of more peripheral actors. Core actors are the officers of the fire services, the medical emergency services, the police, the municipality, the team leader and the information manager. These roles have been described in section 3.3. The selection of additional actors for the *Westerschelde Tunnel* hazardous materials scenario consists of a tunnel guard, a tunnel emergency coordinator, a fire service advisor on hazardous materials, the mayors from the municipalities involved (*Borssele* and *Terneuzen*), a press officer from the police, a fire service commander, and possibly a second police officer for traffic management. Some of the additional actors were present during the exercises while others were role played by the exercise staff. The tunnel guard, the tunnel emergency coordinator, and the advisor on hazardous materials were present. The two mayors, the press officer, and the second police officer were role-played. An overview of the emergency response actors in the *Westerschelde Tunnel* hazardous materials scenario is provided in table 3.3.

Actor	**Appearance in the *Westerschelde Tunnel* hazardous materials scenario**
Fire services	Present
Medical emergency services	Present
Police	Present
Municipality	Present
On-scene command team leader	Present
Information manager	Present
Tunnel guard	Present
Tunnel emergency coordinator	Present
Advisor on hazardous materials	Present
Press officer	Role-played
Fire service commander	Role-played
Mayor(s)	Role-played
Second police officer	Role-played

Table 3.3 - Emergency response actors in the *Westerschelde Tunnel* hazardous materials scenario

The tunnel guard is an employee of the *Westerschelde Tunnel* operator and is responsible for the operational response to emergencies. A tunnel guard is permanently available at the tunnel and deals autonomously with minor incidents. In case off large-scale accidents, the tunnel guard supports the emergency services that are alarmed. The tunnel guard has technical expertise that can be helpful to the emergency services. The tunnel guard can, for example, adjust the ventilation system in the tunnel to reduce the airflow or noise at the accident location. The tunnel guard is responsible for salvage and recovery operations and a safety check before the tunnel can reopen after an accident. The emergency coordinator is also an employee of the *Westerschelde Tunnel* operator and coordinates the response to accidents from the tunnel operations center. While the tunnel guard manages accidents on-site, the emergency coordinator stays in the operations center and manages the effects of the accident. The tunnel guard can be part of an on-scene command team. The emergency coordinator can take place in the Regional Operational Team when the response organization is scaled-up to a *GRIP 2* situation or higher. The advisor is an expert on hazardous materials and has equipment for specific measurements. The advisor plays a crucial role in the *Westerschelde Tunnel* hazardous materials scenario, as he supports the fire services and determines whether the accident site is safe or not.

The press officer is a member of the police. A press officer from the police is normally responsible for contacts with the media and the spread of information to the public at large during large-scale emergencies. This role is small in virtual reality exercises since there is no simulated contact with the media. The role of the press officer is role-played by the exercise staff when the emergency response actors involved in the exercise want to communicate with the media. The fire services advisor on hazardous materials is alarmed when emergencies involve advanced hazardous materials. The fire service commander is the commander of the first fast response unit that arrives at the accident. He or she has the lead over monodisciplinary tasks of the fire services and reports to the fire service officer. The fire service commander is the main source of information for the fire service officer in the *Westerschelde Tunnel* hazardous materials scenario.Mayors are in charge of emergency response in the Dutch incident command system. In GRIP 1 or GRIP 2 situations, mayors are in principle only informed about the operational response operations. In the *Westerschelde Tunnel* hazardous materials scenario, the mayors do not actively participate in the response organization but communicate with the on-scene command team though the municipal officer or the team leader. The police can decide to alarm a second officer because accidents in the *Westerschelde Tunnel* have a disruptive effect on the traffic in the environment of the tunnel. The task of traffic management can be allocated to the second officer as the simultaneous management of processes inside and outside the tunnel can be too much work for one officer. When a second officer is alarmed, the exercise staff role-plays this actor and takes over the traffic management task.

The challenges: emergency response tasks in the Westerschelde Tunnel hazardous materials scenario

The *Westerschelde Tunnel* hazardous materials scenario involves an extensive set of tasks for the emergency response organization. The tasks that are part of the emergency response in the *Westerschelde Tunnel* hazardous materials scenario are listed in table 3.4.

Emergency response task	Mono or multidisciplinary	Responsible actor(s)
Firefighting and containing hazardous materials	Monodisciplinary process	Fire services
Rescue and technical assistance	Monodisciplinary process	Fire services
Measuring	Monodisciplinary process	Fire services
Medical care	Monodisciplinary process	Medical emergency services
Criminal / forensic investigation	Monodisciplinary process	Police
Traffic management	Multidisciplinary process	Police, tunnel operator
Escorting	Multidisciplinary process	Police, medical emergency services, fire services
Registration	Multidisciplinary process	Municipality, medical emergency services, police
Evacuation	Multidisciplinary process	Municipality, medical emergency services, police
Shelter	Multidisciplinary process	Municipality, medical emergency services, police

Table 3.4 - Emergency response tasks in the *Westerschelde Tunnel* hazardous materials scenario

There is a task that plays a prominent role in the *Westerschelde Tunnel* hazardous materials scenario that is not on the standard list of emergency response tasks. The recovery of the tunnel – salvage operations, drainage of hazardous materials, cleaning, and a safety check – is a task that is taken care of by the tunnel operator. This task is unique for tunnels and is therefore not part of the standard list of emergency response tasks. During 'normal' road accidents, the road network operator (*Rijkswaterstaat*) takes care of the recovery task. As the *Westerschelde Tunnel* is privately operated, the tunnel operator is responsible for the recovery task. The task of recovery operations is added to the list of tasks in the *Westerschelde Tunnel* hazardous materials scenario:

Emergency response task	Mono or multidisciplinary	Responsible actor(s)
Recovery operations	Monodisciplinary process	Tunnel operator

The *Westerschelde Tunnel* hazardous materials scenario involves a variety of monodisciplinary tasks that are taken care of by individual emergency response actors. The most important tasks in the scenario are firefighting, containing hazardous materials, rescue and technical assistance, measuring, providing medical care, and criminal and forensic investigation. Firefighting and rescue are tasks of the fire services alone. Because the fire services are the only discipline allowed to enter the accident-tunnel at the initial stages of the emergency response, other disciplines cannot provide support (the tunnel guard would be able to provide advice for containing hazardous materials or technical assistance and the medical services could help with the rescue operations). Measuring is a task of the fire services and the advisor on hazardous materials. Because the advisor on hazardous materials is a member of the fire services, this task is characterized as monodisciplinary. Providing medical care is a task of the medical emergency services. This task includes triage, the treatment of lightly wounded victims at the accident location, and transport of heavily wounded victims to local hospitals. Criminal and forensic investigation is a task of the police. Depending on the characteristics, size, and consequences of an accident, the investigation can also involve the forensic institute or the public prosecutor. Involvement of these actors would alter the task considerably. However, as the *Westerschelde Tunnel* hazardous materials scenario does not include severe damage or fatalities, these actors have not been included. The remaining tasks in the *Westerschelde Tunnel* hazardous materials scenario are managed by multiple emergency response actors.

Traffic management is a shared task of the police and the tunnel operator. Activation of the emergency system by the tunnel operator results in automatic rerouting of traffic at highways and the main access roads to the tunnel. However, local traffic needs to be managed ad hoc and the police has to monitor the overall traffic situation in consultation with the tunnel operator and possibly the road network operator. Escorting is a shared process of the police and the medical emergency services, and possibly the fire services. The main concern in the *Westerschelde Tunnel* hazardous materials scenario is that ambulances that are heading for the tunnel or from the tunnel to local hospitals will get stuck in the heavy traffic. If this is the case, the medical emergency services and the police have to cooperate to get ambulances through in time. The emergency response tasks registration, evacuation and shelter are all three jointly managed by the municipality, the medical emergency services, and the police. The responsibility for evacuation and shelter lies with the local municipality. The municipality arranges location for shelter and transport from the emergency scene to the shelter location. However, the decision whether people can be evacuated to the shelter, need medical treatment at the emergency scene, or transport to a hospital is made by the medical services. In practice, local municipalities often lack the resources to guide a large-scale evacuation under emergency conditions and the municipal officer is likely to arrive relatively late at an emergency scene. The police is therefore expected to initially pick up the process and provide assistance to create an orderly evacuation. Recovery operations are the responsibility of the tunnel operator but in practice take place in cooperation with the fire services. Because the fire services are initially the only party allowed in the accident tunnel, the tunnel operator relies on the information of the fire services to determine what material is needed to remove the collided vehicles from the tunnel.

Chapter two describes how emergency response can be divided into an early, initial, and final stage. Depending on the emergency scenario, emergency response tasks will typically be part of specific stages with some variation from how participants manage the tasks in a particular exercise. To create an overview of what happens approximately at what moment during the *Westerschelde Tunnel* hazardous materials scenario, the response tasks are linked to specific stages of the emergency response.

Initial tasks are tasks that can be initiated right from the beginning of the scenario. Intermediate tasks can be initiated when initial tasks are running or have finished and can be finished before the scenario ends. And final tasks are tasks that take place at the end of a scenario. All three types of tasks can be either monodisciplinary or multidisciplinary. At what moment of the response to an emergency a task can be performed is largely dependent on interdependencies between different tasks. Initial tasks can regularly start independently from other tasks. Intermediate tasks can often only start when initial tasks are taking place or have been completed. And final tasks are generally dependent upon the successful completion of initial and intermediate tasks.

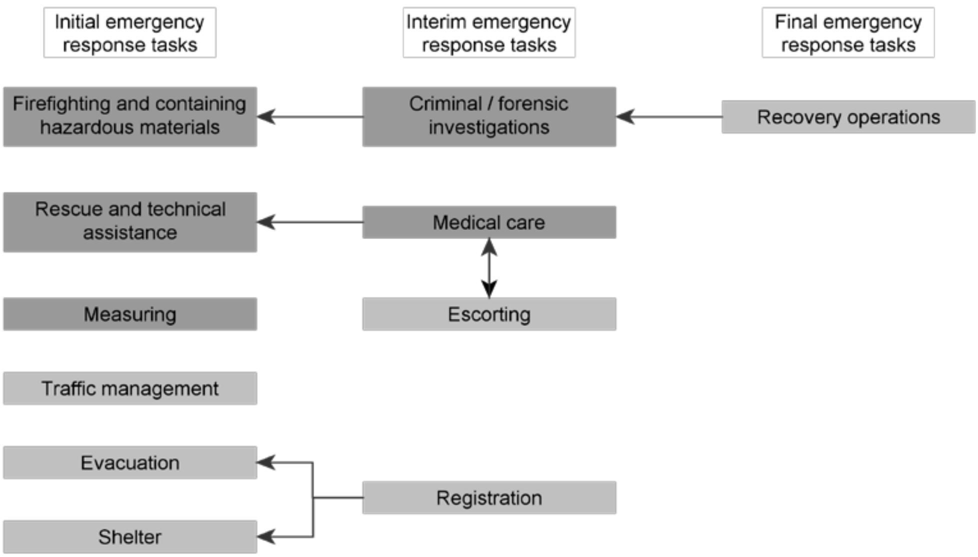


Figure 3.6 - Interdependencies between emergency response tasks in the *Westerschelde Tunnel* hazardous materials scenario

The initial tasks in the *Westerschelde Tunnel* hazardous materials scenario can all start independently. Firefighting and containing hazardous materials, rescue and technical assistance and traffic management can start right from the beginning of the emergency response. Measuring is likely to start a little later as it is dependent upon the arrival of the advisor on hazardous materials. The same counts for evacuation and shelter that are managed by the municipal officer that generally arrives later than the emergency services.
The intermediate tasks criminal and forensic investigation and medical care are dependent upon initial tasks. Investigation depends on the containment of hazardous materials and medical care on rescue. Escorting and medical care are dependent on rescue and on each

other in the sense that the two tasks can only jointly take place. Registration generally takes place after evacuation and shelter are arranged. However, depending on how the registration tasks is arranged, it can also take place within the tunnel or during the evacuation.

Final tasks are dependent on the completion of several earlier tasks. Recovery operations can only take place when criminal or forensic investigation is completed. Because investigation is dependent on the containment of hazardous materials, a chain of processes exists that can only be executed in the right order. Recovery operations include salvage operations and the draining hazardous materials. Within the recovery task, the drainage of hazardous materials is dependent upon salvage operations. Figure 3.6 shows the tasks in the *Westerschelde Tunnel* hazardous materials scenario. The arrows between the tasks indicate the interdependencies between different tasks.

It is possible to specify beforehand what moments in the *Westerschelde Tunnel* hazardous materials scenario are important for multidisciplinary coordination, based on the scenario description and the analysis of response tasks. The key concern in the initial stages of the scenario is whether the tunnel is safe for the emergency responders. Emergency responders need access to the accident tunnel to perform rescue, evacuation and medical care. The fire services have to assess the safety of the situation at the accident scene and other actors have to await their judgment. The fire services obtain information about the situation in the accident tunnel that is useful for the other emergency services. The medical emergency services want to know about victims, both their numbers as their injuries, to arrange adequate medical care and transport. The municipality wants to know about the number of persons that needs to be evacuated and sheltered. The police and the tunnel operator want to know how and when the other services need assistance and how long the tunnel will be closed so they can take adequate traffic management measures. In sum, information is a scarce resource in the beginning of the scenario and the fire services is the only actor that has direct access to the emergency scene. Early coordinative efforts can take different forms, depending on the course of events and the decisions of the actors involved. One possibility is that the actors involved organize a first on-scene command team meeting early in the exercise. As soon as one of the officers involved scales the emergency response up to GRIP 1, and an on-scene command team leader arrives at the scene, the first on-scene command team meeting can take place. Another possibility is that the emergency services present at the scene gather in a field meeting. This ad hoc meeting can be used to coordinate an initial response before a first on-scene command team meeting can be arranged. A third option for the emergency services is to coordinate the response in a less centralized way by arranging bilateral or trilateral meetings regarding specific response tasks.

Considering the different tasks in the scenario and the interdependencies between actors and tasks, it is possible to guess beforehand what interactions and what roles are important in the scenario. A explained above, the fire services play a crucial role in the scenario as it is the only actor that is initially allowed to enter the accident tunnel. In this way, the fire services form the eyes of the response organization. The centrality of the fire services in the response communication network is therefore an interesting factor to analyze. Another interesting role is played by the tunnel guard. Having expert knowledge on the tunnel, he can provide valuable information during the emergency response. The extent in which the other actors use this expertise and how the tunnel guard is adopted within the emergency response organization is another interesting factor. Subgroups are likely to form around the multidisciplinary tasks (traffic management, escorting, registration, evacuation and shelter). The clustering in the communication network of the actors involved in these processes is another interesting variable for analysis.

3.5.2 The Westerschelde Tunnel evacuation scenario

The narrative: large-scale evacuation from the Westerschelde Tunnel

The *Westerschelde Tunnel* operator has reported a collision in the eastern tunnel. The collision has happened somewhere between cross-passage 22 and 23 and involves multiple vehicles. Fire seems to have broken out in one of the cars involved, because smoke is accumulating in the tunnel. The smoke blocks the view of the tunnel operator via the tunnel video-monitoring system on the accident scene. It is therefore difficult to provide more information on the situation.

The tunnel operator activates the alarm system. The ventilation in the tunnel is intensified to remove as much smoke as possible. The emergency services are summoned to the tunnel in accordance with the *Westerschelde Tunnel* emergency response plan. Fast response units of the fire services go towards the accident location. Other units of the fire services drive to the tunnel and wait for further instruction at the deployment positions at the tunnel entrances. The medical emergency services send two ambulances and the first unit of the police arrives together with the fire services. The municipality is warned to send an officer to deal with a possible evacuation. The tunnel guard has driven into the non-accident tunnel and waits for further instructions from the fire services.

Touring-car - The fire service commander of the fast response unit reports about the emergency situation to the fire services officer. He tells the fire service officer and the tunnel guard that six vehicles are involved in the accident, including a touringcar and a police van. One passenger car has caught fire and a person is trapped in another passenger car. Both the touringcar and the police van seem to be empty, although the smoke and noise made by the ventilation systems make it difficult to obtain an overview of the situation. The commander asks the officer to send fire engines into the accident tunnel to take care of the fire. Because of the smoke, people who got stuck behind the accident have left their cars and used the cross-passages to escape to the non-accident tunnel. These people have grouped in the non-accident tunnel and await further instructions. Some have respiratory problems due to the smoke so the fire service officer calls for the medical emergency services to provide assistance.

Traffic jams - Closing down the tunnel leads to traffic jams at both sides of the tunnel. The tunnel operator has started the automatic detour system but this does not stop all traffic from driving to the tunnel. The police have to send surveillance units to the toll-squares at both sides of the tunnel to manage the traffic. The police officer is noticed by the emergency dispatch center that the police van that was involved in the collision was used to transport two convicted criminals to a penitentiary. Now that the van is empty, the two seem to have escaped. Meanwhile, the municipal officer has arrived at the deployment position and learns that the touringcar was used by a home for senior citizens for a day-trip. Most of the senior citizens have gone to the non-accident tunnel but a few are still in the accident tunnel or the cross-passages and suffer from respiratory problems. The municipal officer starts to arrange a shelter location and tries to contact the other officers to start evacuating people. When the smoke in the accident tunnel begins the fade, the tunnel operator notices on the video-monitoring system that two persons are walking through the accident tunnel to the northern exit.

Evacuation and rescue - When the fire services succeed in extinguishing the fire in the passenger car the smoke quickly starts to disappear. The municipality has contacted the touringcar operator and it turns out that the touringcar had 45 passengers on board. By now, all passengers are brought to the non-accident tunnel. Twenty of them have respiratory problems and four are partially suffocated. The medical emergency services have set up a wounded shelter in the non-accident tunnel to take care of victims. In the other vehicles involved in the collision five people have been injured. Two suffer from severe injuries and one is still trapped in his car. The fire services try to bring all victims to the non-accident tunnel as soon as possible. The three severely wounded victims need to be picked up at the accident location. The fire services ask for an ambulance to drive into the accident tunnel. The fire services successfully rescue the person that is trapped in a car and hand him over to the medical emergency services. There are no people left in the accident tunnel. The medical services are organizing the transport of victims to local hospitals, but ambulances get stuck in the traffic. The police starts to escort ambulances to reach the tunnel.

Clearing the mess - In the meantime, the police receives a message from *Ellewoutsdijk*, a small village near the tunnel's northern entrance. The two fugitives have tried to hijack a car. The *Westerschelde Tunnel* operator is receiving calls from local industry asking for a prognosis of the duration of the accident and tunnel closure. An important question for the tunnel operator is how severely damaged the cars involved in the collision are. The tunnel operator has to organize salvage operations and pulling out the touringcar requires specific salvage equipment. The tunnel guard ask the fire services if he is allowed to enter the accident tunnel to inspect the situation. Measurements of the fire services show that the accident scene is safe so the tunnel guard, and the other emergency services, can do their work at the emergency site. The police starts the forensic investigation, to determine the cause of the accident, and focuses especially on the van transporting the convicted criminals. Outside the tunnel, the municipality has arranged a shelter location for victims near *Terneuzen*. People involved in the accident have been brought to the shelter location by buses, ambulances and the police. The municipal officer is registering everybody who arrives at the shelter locations to make sure that nobody is missing. The tunnel operator wants to reopen the tunnel as soon as possible. A line of cars is still parked behind the accident. The cars have to be removed before the tunnel can be reopened. The police starts to list passengers that can be brought back to their cars and to list the cars that need to be towed away. As the situation is quickly getting better, the on-scene command team discusses whether the response operations should be moved to the accident tunnel so the non-accident tunnel can be reopened for traffic.

The players: actors in the Westerschelde Tunnel evacuation scenario

Similar to other scenarios, the emergency response organization in the *Westerschelde Tunnel* evacuation scenario consists of a core group and various additional actors. The actors that play a part in the scenario are listed in table 3.5. The roles of the additional actors are briefly discussed.

Actor	**Appearance in the *Westerschelde Tunnel* evacuation scenario**
Fire services	Present
Medical emergency services	Present
Police	Present
Municipality	Present
On-scene command team leader	Present
Information manager	Present
Tunnel guard	Present
Tunnel emergency coordinator	Present
Fire Service Commander(s)	Role-played
Second police officer(s)	Role-played
Touringcar operator	Role-Played

Table 3.5 - Emergency response actors in the *Westerschelde Tunnel* evacuation scenario

The first actor added is the tunnel guard. The tunnel guard takes care of the operational response of the *Westerschelde Tunnel* operator in case of emergencies. His official role has elaborately been described in the *Westerschelde Tunnel* hazardous materials scenario. The role of the tunnel guard is more extensive in the *Westerschelde Tunnel* evacuation scenario as compared to the *Westerschelde Tunnel* hazardous materials scenario. This is due to the fact that the tunnel guard is allowed to enter the accident tunnel at an earlier stage in the evacuation scenario, and can start the recovery operations sooner. The role of the emergency coordinator, who is responsible for emergency response at higher levels of the *Westerschelde Tunnel* operator, is similar to his role description for the *Westerschelde Tunnel* hazardous materials scenario. The tunnel guard and the tunnel emergency coordinator are the only additional actors that are present during the exercises. All other additional actors are role-played by the exercise staff.

The emergency response organization in the *Westerschelde Tunnel* evacuation scenario includes several fire service commanders. The commanders play an important part in the monodisciplinary operational response of the fire services. In the early stages of the emergency, the commanders are the only emergency responders in the accident tunnel and therefore play a crucial role in establishing an accurate view of the situation. The commanders are the only responders that can assess the damage and the number of casualties. The fire service commanders are role-played by the fire service exercise staff. Halfway during the exercise, the police can call for a second police officer. His task can be to manage traffic around the tunnel, to take care of the fugitives that have escaped from the police van and left the tunnel, or both. In the most extreme case, the police can ask for two additional officers, one for traffic management and one for tracing the fugitives. The additional officers are role-played by the police exercise staff. The last actor added is the touringcar operator. The touringcar operator is mainly a source of information for the response organization as he can provide information on the number and background of the people present in the touringcar. The touringcar operator can be contacted by all other actors in the exercise if they are searching for information. The touringcar operator is role-played by the exercise staff of the actor that is requesting information.

The challenges: emergency response tasks in the Westerschelde Tunnel evacuation scenario

The *Westerschelde Tunnel* evacuation scenario involves a varied set of emergency response tasks. Similar to the analysis of the *Westerschelde Tunnel* hazardous materials scenario, these tasks are divided in monodisciplinary and multidisciplinary tasks and described in terms of interdependencies and dynamics. The emergency response tasks that are part of the evacuation scenario are listed in table 3.6.

Emergency response task	Mono or multidisciplinary	Responsible actor(s)
Firefighting and containing hazardous materials	Monodisciplinary process	Fire services
Rescue and technical assistance	Monodisciplinary process	Fire services
Measuring	Monodisciplinary process	Fire services
Medical care	Monodisciplinary process	Medical emergency services
Criminal / forensic investigation	Monodisciplinary process	Police
Traffic management	Multidisciplinary process	Police, tunnel operator
Escorting	Multidisciplinary process	Police, medical emergency services, fire services
Registration	Multidisciplinary process	Municipality, medical emergency services, police
Evacuation	Multidisciplinary process	Municipality, medical emergency services, police
Shelter	Multidisciplinary process	Municipality, medical emergency services, police

Table 3.6 - Emergency response tasks in the *Westerschelde Tunnel* evacuation scenario

Similar to the hazardous materials scenario, the *Westerschelde Tunnel* evacuation scenario involves a core task that is not part of the list of standard emergency response tasks: recovery operations. Recovery operations are primarily a task of the *Westerschelde Tunnel* operator but take place in cooperation with the fire services. Recovery operations are extensive in the evacuation scenario and are therefore likely to require cooperation and coordination.

Emergency response task	Mono or multidisciplinary	Responsible actor(s)
Recovery operations	Monodisciplinary process	Tunnel operator

The monodisciplinary processes in the *Westerschelde Tunnel* evacuation scenario are firefighting and containing hazardous materials, rescue and technical assistance, measuring, medical care and criminal or forensic investigation. Firefighting is an exclusive task of the fire services and takes place early in the scenario. As the fire is relatively small, the task requires little time and can be finished soon. There are no hazardous materials involved in the accident so the entire task of firefighting and containing hazardous materials can be finished early on the in the exercise. Rescue and technical assistance is an extensive task in the evacuation scenario. As long as smoke is obstructing emergency operations in the accident tunnel, the fire services have to evacuate victims to the non-accident tunnel for further medical care. Also, with a person trapped in a vehicle, the rescue task continuous as long as this person has not been transported to a hospital. As the person trapped is seriously injured, the rescue operations requires coordination between the fire services and the medical emergency services. The rescue task is monodisciplinary but requires extensive coordination. Measuring is a relatively straightforward monodisciplinary task of the fire services. The commanders in the accident tunnel measure the intensity of the smoke in the tunnel to determine whether it is safe to allow other emergency responders to set foot on the emergency scene. The measuring task ends shortly after the fire is extinguished. Medical care is provided by the medical emergency services. The medical emergency services decide whether victims are handed over to the municipality for evacuation or need to be transported to local hospitals. The transport of victims requires escorting which is described as a multidisciplinary process. The forensic investigation can start as soon as the fire services have reported that the accident tunnel can safely be entered by emergency responders. As the task requires extra care due to the involvement of the police van, it might take longer than usual. The forensic investigation task must be finished before the tunnel can be reopened. Tracing the fugitives is also an important monodisciplinary process of the police. However, the tracing can be done by an officer that is role-played by the exercise staff. The tracing process has therefore not been included in the analysis.

Multidisciplinary tasks in the *Westerschelde Tunnel* evacuation scenario are traffic management, escorting, registration, evacuation, shelter, and recovery operations. Traffic management is relatively straight forward as the tunnel operator activates an automatic diversion system when the tunnel is closed and the emergency services are alarmed. The management of local traffic at the tunnel entrances requires some additional efforts from the police. Certainly when emergency response vehicles threaten to get stuck at the access roads, the police has to make sure that the tunnel remains accessible. Traffic management is therefore perceived as a multidisciplinary task of the tunnel operator and the police. The task of guiding ambulances through traffic is referred to as escorting. This process is relevant in later stages of the scenario when victims are transported to local hospitals. Escorting is not necessarily restricted to ambulances and is also relevant for the salvage trucks that have to come from other locations in the region. Escorting is therefore a multidisciplinary task of the police, the medical emergency services and possibly the tunnel operator who coordinates the salvage operations. The tasks of evacuation and shelter are organized by the municipality, medical emergency services and the police together. The municipality is primarily responsible for the care for non-injured victims. In practice, assistance from other emergency services is required. The same counts for registration, a task formally taken care of by the municipality. In the field, the medical emergency services and police start to gather information from the victims at an earlier stage, so cooperation between the emergency services involved in this process is desirable. Recovery operations are organized by the *Westerschelde Tunnel* operator. The assessment of the damage is done in cooperation with the fire services. The scenario includes a possibility to open the non-accident tunnel as soon as possible while continuing the recovery operations in the accident tunnel. This decision affects the traffic management process, adding to the multidisciplinarity of the recovery operations.

The initial tasks in the *Westerschelde Tunnel* evacuation scenario can be started independently from other tasks. Although the rescue of the person trapped in a vehicle has to wait for the fire to be extinguished, the rescue of non-trapped persons takes place right from the start of the scenario. The intermediate tasks are all dependent upon other tasks. Measuring starts after the fire has been extinguished. Registration is dependent upon evacuation and is likely to take place at the shelter location. Medical care is dependent upon rescue as the medical emergency services are initially not allowed to enter the accident tunnel. After triage, the victims are either send to local hospitals or handed over the municipality for transport to the shelter location. The escorting task by definition takes place in parallel with the medical care and is likely to last as long as the recovery operations require. The final tasks are dependent upon many of the earlier tasks. Forensic investigation is dependent on firefighting and measuring. Medical care has no effect on the investigation tasks as the two tasks can take place simultaneously. Recovery operations can only start when the fire is extinguished, victims are rescued, treated or evacuated, and forensic research is finished. However, as recovery operations require damage assessment and the arrival of large salvage equipment, the task can start before the actual salvage work at the accident location is done. The interdependencies between the different emergency response tasks are shown in figure 3.7.

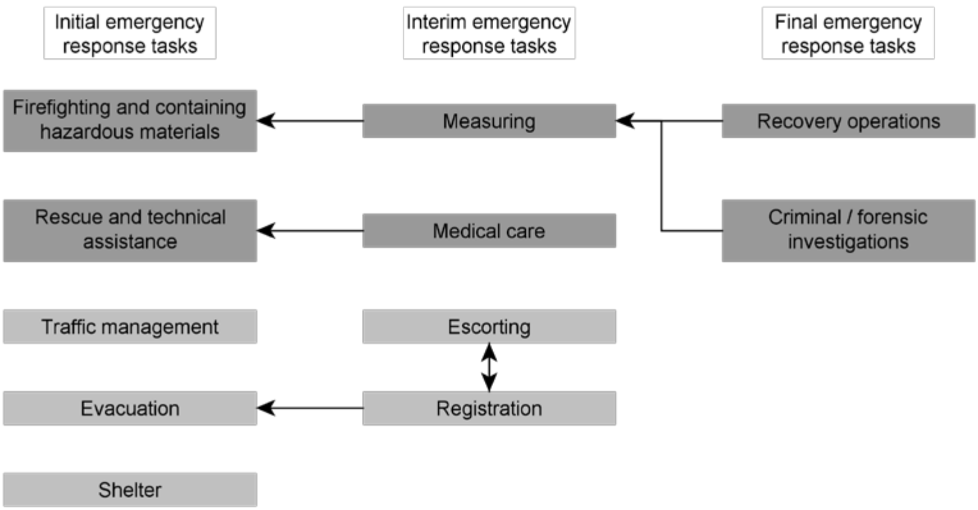


Figure 3.7 - Interdependencies between emergency response tasks in the *Westerschelde Tunnel* evacuation scenario

Considering the *Westerschelde Tunnel* evacuation scenario description and the analysis of actors and tasks involved, it is possible to point out moments in the response that specifically demand coordination. At the early stages of the exercise, the main challenge for all actors in the response organization is to obtain information. Similar as in the *Westerschelde Tunnel* hazardous materials scenario, the fire service commanders are initially the only actors allowed at the accident scene. The commanders report to the fire service officer who thereby obtains information that is relevant for all actors. The initial information includes the number of victims, which is relevant for the medical emergency services and the municipality, and the severity of the damage, relevant for the tunnel operator, the police and the municipality. The fact that the fire services are the first to obtain information creates an early dependency of the response organization on the fire services.

Sending the alarm message of the *Westerschelde Tunnel* to the emergency services, the emergency dispatch center is likely to call for a GRIP 1 level response immediately. The presence of multiple cars and a touringcar calls for a large-scale response. However, if the dispatch center does not call for GRIP 1, one of the officers will probably do. As soon as GRIP 1 is established, the on-scene command team leader is alarmed. To accommodate the exchange of information and the development of an initial response, the officers present at the tunnel can ask for a first on-scene command team meeting to be arranged or gather in a field meeting.

At the start of the exercise, the priority is to extinguish the fire and get rid of the smoke in order to make the accident location safe for emergency responders. This process is taken care of by the fire services. At the same time, the police hears about the convicted criminals that have escaped from the van. This poses another treat to the emergency workers, certainly to the fire services that work at the accident site. The safety of the emergency responders has to be guaranteed and the police will have to trace the fugitives as soon as possible. This results in a dependency of the emergency response organization on the police. The uncertainty about the fugitives lasts until the tunnel operator sees them on the tunnel monitoring system when they exit the tunnel. From that moment, the emergency responders can continue their work and the police can hand the hunt for the fugitives over to another officer. From this moment, the fire services have to determine whether the accident location is safe and other emergency response tasks can be started. Measuring is therefore a short but critical process in the scenario.

The presence of the touringcar with senior citizens requires a large-scale evacuation. Evacuation is a task of the municipality in cooperation with the tunnel operator, the medical services and the police. The process starts right from the beginning of the exercise and lasts until the last victim is out of the tunnel. The task requires continuous coordination between the actors involved to make sure that all victims are evacuated. Recovery operations are, in a similar way, executed by the tunnel operator in coordination with the police and the fire services. This task starts right when the fire services declare the tunnel safe for emergency responders to enter. Damage assessment requires coordination between the fire services and the tunnel guard while the organization of salvage trucks is done in cooperation with the police. The recovery operations require continuous coordination from halfway the accident until the exercise finishes.

3.5.3 The urban hazardous materials scenario

The narrative: explosive threat in an urban environment

The emergency dispatch center calls for all emergency services to go to a fire that has been reported on a ship at the *Loskade* in Middelburg. The fast response units of the fire services are already at the scene and are taking preparations to fight the fire. Rumor goes that an explosion has occurred at the engine room and that people are injured. It is unknown whether, and how many passengers are on board or whether they have left the ship. The fire services officer is the first officer to arrive at the *Loskade*. A fire service commander reports to him that an explosion has indeed taken place and that the ship's chief engineer is missing. It is unknown whether more people are wounded or whether passengers are missing or not. When the commander finishes his report, officers from the other emergency services arrive as well.

Thick smoke - The weather is calm, 18 degrees Celsius, with a light wind from the south-west. The fire at the ship is smoking heavily and the wind is carrying thick smoke along the canal towards the industrial area of *Ramsburg*. Because of the smoke, the emergency services are summoned to gather at the south side – the downwind side – of the ship. It is unclear whether the smoke contains hazardous materials. Because of the thickness of the smoke and the possible presence of asbestos the fire services alarm the hazardous materials advisor to take measurements.

The municipality is contacted by companies from the *Ramsburg* industrial area. The smoke is causing problems and people want to know whether they have to leave the area or close their windows. In the meantime, the medical emergency services prepare to take in a large group of passengers with respiratory problems. They ask the emergency dispatch center for additional ambulances to transport possible victims. There is only one victim yet but given the size of the ship, the emergency services expect more victims to be found. The situation is uncertain and chaotic. It is unclear whether there are still passengers on board of the ship, whether the smoke is toxic, and how many people are missing.

Go in / get out - The fire at the ship starts to swell despite the firefighting that has started. Soon, the entire front-end of the ship is on fire. A fire service commander notices a container at the deck that contains gas cylinders. The cylinders have to be removed as quickly as possible to avoid an explosion. This is not without danger. An exploding cylinder can cause much damage in the direct environment of the ship and poses a threat to the emergency responders at the scene. The fire services are facing the choice to abandon the ship or to try to remove the container. Another possibility is to cool the container as much as possible. The firefighters that are still on the ship find five passengers on a lower deck and guide them to the quay. They are handed over to the medical emergency services. The chief engineer is dead and lies in the engine room. Because of the growing fire, the fire services cannot get the body out. The medical emergency services have to send one of the victims over to a local hospital for treatment and set up a wounded shelter to accommodate the others. The five passengers found on the ship suffer from respiratory problems as a result of the thick smoke. Two more passengers are found on board of the ship a little later. They have burns and are send to a local hospital right away.

Smoke is everywhere - The ship is still smoking fiercely and the measurements of the advisor on hazardous materials must point out whether hazardous materials are in the smoke. If the smoke turns out to be toxic, people suffering from breathing difficulties need to get further medical treatment. Because of the different possible scenarios, the medical services keep their victims in the wounded shelter until the fire services can provide clarity. The police receives messages that the smoke is hindering traffic at the N57, a main road that connects Middelburg with the northern parts of *Zeeland* and that runs through the *Ramsburg* industrial area. The smoke is causing trouble at the entrance of the *Dampoort* viaduct. Drivers cannot see the other side of the tunnel because of the smoke and have blocked the road. Smoke is also causing trouble along the canal and the police has to take measures for managing traffic. The canal is closed and the waterway authority is warned to close down all traffic. The N57 is partially closed by the police. The situation regarding the missing passengers is still unclear. Advisors of the mayor want to scale up the emergency response organization to GRIP 3. The large number of missing passengers is attracting the attention of the media and the municipality wants to setup a policy team. The officers at the scene do not know about this decision and keep searching for the missing passengers. The situation at the ship is getting worse. The fire is extending and the fire services have to leave the ship. The presence of the gas cylinders is hampering the response. The advisor on hazardous materials gives the advice to evacuate the area around the ship. If the cylinders explode, windows will shatter and people standing behind the windows watching the incident will get hurt. The advice is to close curtains to prevent glass from flying into houses in case of an explosion.

GRIP 3? - The fire services gain control over the fire, also because the ship has partially sunk into the canal. As far as the fire services know, there are no passengers left on board except for the chief engineer who is lying in the engine room. The medical emergency services encounter a large group of passengers that return from the city center and are heading back to the ship. The municipality has obtained a list of passengers from the shipping company. But even with the returning passengers, the list is not complete. The police have told some passengers to wait in a nearby restaurant and the medical services have send some passengers to local hospitals. Only when the three services carefully add up their numbers, they can figure out whether all passengers have been found. The need to scale up to GRIP 3 is no longer there but the on-scene command team has to start taking measures for environmental care as the ship might start leaking in the canal.

The players: actors in the urban hazardous materials scenario

The core members of on-scene command teams are all present in the urban hazardous materials scenario. The municipal officer has an exceptionally large role as he is responsible for registering the large group of passengers. The same counts for the advisor on hazardous materials that has a crucial role in the scenario. The advisor is called to take measurements of the thick smoke that comes from the ship. Soon after, the threat of an explosion is added to his concerns. His decisions are crucial to the entire response organization.

The first additional actor is the fire service commander. The fire service commander is already present at the emergency scene when the first officers arrive and forms a valuable source of information. The commander is role-played by the exercise staff of the fire services. A shipping company liaison is present in the scenario as well to provide information on the ships technical specifications and the passengers. The liaison provides information to the fire services. The passenger lists are of interest to the municipal officer, the medical emergency services and the police. The shipping company liaison is role played by the exercise staffs of the different disciplines involved in the exercise. The last additional actor that has a role in the urban hazardous materials scenario is the mayor. As the municipality considers to scale up the emergency response to a GRIP 3 situation, a policy team needs to be formed which is headed by the mayor. The mayor plays an important role as he is frequently in contact with the on-scene command team leader to discuss the situation and possible risks. The mayor is role-played by the exercise staffs of the municipal officer and the on-scene command team leader. The emergency response actors in the urban hazardous materials scenario are shown in table 3.7.

Actor	**Appearance in the urban hazardous materials scenario**
Fire services	Present
Medical emergency services	Present
Police	Present
Municipality	Present
On-scene command team leader	Present
Information manager	Present
Advisor on hazardous materials	Present
Fire service commander	Role-played
Shipping company liaison	Role-played
Mayor	Role-Played

Table 3.7- Emergency response actors in the urban hazardous materials scenario

The challenges: emergency response tasks in the urban hazardous materials scenario

The urban hazardous materials scenario involves twelve of the standard emergency response tasks. The tasks are listed in table 3.8.

Emergency response task	Mono or multidisciplinary	Responsible actor(s)
Firefighting and containing hazardous materials	Monodisciplinary process	Fire services
Rescue and technical assistance	Monodisciplinary process	Fire services
Measuring	Monodisciplinary process	Fire services
Medical care	Monodisciplinary process	Medical emergency services
Criminal / forensic investigation	Monodisciplinary process	Police
Traffic management	Multidisciplinary process	Police, road network operator
Escorting	Multidisciplinary process	Police, medical emergency services, fire services
Registration	Multidisciplinary process	Municipality, medical emergency services, police
Evacuation	Multidisciplinary process	Municipality, medical emergency services, police
Shelter	Multidisciplinary process	Municipality, medical emergency services, police
Environmental care	Multidisciplinary process	Fire services, municipality

Table 3.8- Emergency response tasks in the urban hazardous materials scenario

The urban hazardous materials scenario presents several extensive monodisciplinary tasks. The task of firefighting and containing hazardous materials is at the core of the emergency response, right from the beginning of the scenario until its end. The firefighting task is exclusively managed by the fire services and has little consequences for other tasks. As the fire gets out of control after all victims have been rescued from the ship, rescue, medical care, and shelter can evolve independently from the firefighting. The task of containing hazardous materials is far more consequential for the development of the scenario. The discovery of gas cylinders at the deck, and the potential presence of toxic substances in the smoke that comes from the ship, have consequences for the emergency response. The tasks of evacuation and warning and alarming the public are solely based on threat from the hazardous materials. The same counts for traffic management that is a consequence of the heavy smoke. The measuring and firefighting tasks are closely linked. Rescue is taken care of by the fire services. Several individuals are rescued in the early stages of the emergency response and handed over the medical emergency services. Because of the arrival of victims with respiratory problems, the medical emergency services start the process of medical care at the location. The task is relatively limited because of the limited number of victims and the light injuries. However, the threat of a large group of victims creates uncertainty about the medical care task until certainty about the whereabouts of the missing passengers is obtained. Because of the death of the chief engineer, the criminal or forensic investigation is extensive. The task is taken care of by the police. The intensive fire and the partial sinking of the ship make that the actual investigation cannot take place immediately. The process, however, is started up as soon as the engineer is found dead and the other passengers are rescued from the ship. Traffic management is a monodisciplinary task of the police and is a consequence of the smoke that comes from the ship. As soon as complaints from the *Ramsburg* industrial area come in, the traffic management task starts. A possible linkage with the waterway operator can be made here as they are responsible for closing down the canal.

Escorting is described as a monodisciplinary task in the standard list of emergency management tasks but takes place in close cooperation between the police and the medical emergency services. The task becomes important when traffic management measures restrict traffic in the surrounding area of the accident and access roads get crowded. Environmental care is also a shared task of two disciplines, the fire services and the municipality. Salvage of the ship requires support from other organizations but these are not included in the scenario as the exercise ends before the actual salvage takes place. Preparation for environmental care are taken during the exercise and are a shared task of the fire services and the municipality. The other multidisciplinary tasks in the urban hazardous materials scenario are taken care of by more than two emergency response actors. Registration, evacuation and shelter are arranged by the municipality in coordination with the police and the medical emergency services. Because the passengers of the ship become dispersed over the wounded shelter, the shelter location and the surrounding city, it is difficult to obtain an accurate view of passenger whereabouts. As the treat from the gas cylinders becomes apparent, the question whether the evacuate the direct surrounding of the ship becomes important. If an evacuation is summoned, it is executed by the fire services in coordination with the police and possibly the municipality. Who is executing the evacuation is primarily a matter of resource availability. The municipality is incapable of a large-scale evacuation and the police and the fire service commander have to determine whether they have sufficient manpower available for the task. Part of the response to the threat of hazardous substances in the smoke is warning and alarming the public. This is done by the police and the fire services and by the municipality that responds to worried calls from the public.

The emergency response in the urban hazardous materials scenario is also divided in initial, interim and final tasks. The initial tasks are firefighting and containing hazardous materials, rescue and technical assistance, medical care, and shelter. All initial tasks can start independently from other tasks with the exception of medical care. Medical care is dependent upon the rescue of victims trapped in the ship. The urban hazardous materials scenario presents a significant set of intermediate tasks. As described above, measuring is a crucial task for the emergency response. Measuring starts independently from other tasks but the outcomes affect many other tasks. The need for escorting is dependent upon the traffic management measures and the outcomes of measuring. Traffic management is dependent upon measurements and the instructions of the hazardous materials advisor. The larger the no-go area, the more extensive the traffic management measures and the larger the need to guide ambulances trough the heavy traffic. Warning and alarming the public and evacuation are dependent upon measuring as well. The tasks become more or less extensive depending on the advice of the fire services. Registration is dependent upon rescue and shelter and lasts until the last passengers have been located. The final tasks include environmental care and criminal and forensic investigation. Environmental care is dependent on firefighting and the measurements of the advisor on hazardous materials. The sunken ship needs to be removed and contamination of the water needs to be limited. The fire services are likely to start these tasks as soon as the sinking of the ship becomes inevitable. The sinking of the ship has consequences for the criminal and forensic investigations, since these become more difficult. The preservation of possible evidence is an aspect that the police can point at during the later stages of the exercise. Besides creating awareness of the importance of the investigations, the investigation itself is an independent and monodisciplinary task of the police. The interdependencies between the emergency response tasks in the urban hazardous materials scenario are shown in figure 3.8.

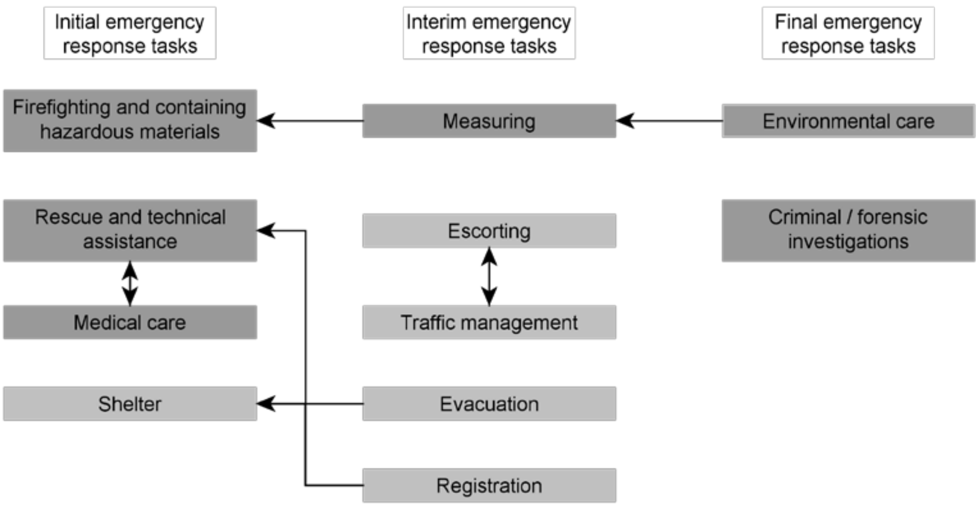


Figure 3.8 - Interdependencies between emergency response tasks in the urban hazardous materials scenario

Given the contents of the urban hazardous materials scenario, there are a few aspects emergency response roles that seem especially interesting. A first interesting set of actors to focus on are the fire services officer and the advisor on hazardous materials. The role of these two actors is crucial for the entire response organization and their position potentially has a significant effect on team performance. For the successful registration of victims, the cluster made by the municipality, the medical emergency services and the police is of interest. The connection between the municipal officer and the fire services officer is interesting with regard to the timely start of the environmental care task. And finally, the role of the on-scene command team leader is interesting to analyze as his management tasks might be needed in translating the advice of the hazardous materials advisor into concrete measures for the other actors involved in the emergency response organization.

The key concern during the urban hazardous materials exercise is whether the emergency scene is safe and whether hazardous materials are spread through the smoke that comes from the ship. The measurements and advice of the advisor on hazardous materials are therefore crucial to all other actors in the response organization. A permanent need for coordination therefore exists between the fire services, including the advisor on hazardous materials, and the other emergency services. Another task that requires extensive coordination is registration. Victims and other passengers of the ship are dispersed over different locations. Obtaining an overview of the whereabouts of all passengers is therefore a challenge. The victims that have been rescued from the ship are accommodated by the medical emergency services, the police takes care of the few non-injured passengers that arrive at the emergency scene, and the municipality eventually accommodates all passengers that need no further hospital care. Obtaining and maintaining an accurate overview of the passengers present and missing requires continuous coordination between the municipality, the medical emergency services, and the police. Environmental care the last task that requires multidisciplinary coordination. The coordination is relatively limited as it only takes place between two actors, the fire services and the municipality, and at the final stages of the exercise.

3.5.4 The port carbon monoxide scenario

The narrative: carbon monoxide poisoning at a ship

It is a cold morning in the early spring. The temperature is below zero and a strong eastern wind makes it feel even colder. At daybreak, a person passing by the port of *Veere* hears someone screaming inside a ship and sees a body lying at the deck. The passer-by calls the police to tell them that something seems to be wrong. The police sends a surveillance unit to the ship to take a look. The surveillance-unit that arrives quickly discovers that something is wrong.

On board of the ship – a large three-master called the *Pride of Veere* – a large number of children is found unconscious. The person that is lying on the deck has passed out as well. When the person on the deck revives, he indicates that some children are missing. The surveillance-unit immediately contacts the emergency dispatch center and asks for assistance from the medical emergency services and the fire services. The large number of people that have fainted indicates carbon monoxide poisoning. However, the emergency services are not sure that this is what happened and the fire services have to take measurements to provide a definite answer. The fire services that arrive at the scene take some quick measurements that reveal high levels of carbon monoxide.

Chaos - It is clear now what has caused the passengers of the ship to faint but the situation is hectic and fuzzy. It is rumored that some children have fallen into the water when they tried to get off the ship. The fire services have to act quickly because of the extreme cold. The local rescue team must be informed to support the search for victims that have fallen into the water. Victims that are found around and inside the ship – mainly children – are brought to the medical emergency services. The number of children that need medical care is vast. The municipal officer has just heard about the incident from the major and is not at the scene yet. The medical services are struggling to create a shelter that is large enough to accommodate everyone that is brought in. In the meantime, the fire services find two people dead while searching the ship inside.

The victims that need medical care are being transported to local hospitals. There are still people missing but it is difficult to determine how many. Nobody seems to know how many children have spent the night at the *Pride of Veere*. The fire services open windows in the ship and use ventilators to remove the carbon monoxide and get fresh air into the different compartments. In the fore-cabin, an engineer is found who has passed out but is still alive. He is handed over to the medical services as well. The fire services continue to take measurements and see that the levels of carbon monoxide are decreasing.

Taking care of the children - The municipal officer arrives at the scene and arranges a shelter location for non-injured victims in a nearby restaurant. Children that do not need any further medical care are brought from the wounded shelter to the restaurant. The children come from a local school and parents that have heard about the situation start to arrive at the scene. The municipality is trying to register the children that are present but the hectic circumstances make accurate registration a challenge. To make sure that no children are still missing, an accurate registration is an absolute must. The lack of oversight is causing a difficult situation as emergency responders are unable to tell parents whether there children are safe or not. What is sure, however, is that no victims are left on the ship except for the two people that have been found dead in one of the compartments. Still, some children need to be transported to a hospital. The roads to the port are narrow and the ambulances are having difficulties reaching the emergency scene. Certainly now that parents are arriving at the scene and park their cars along the access roads. The police has to escort ambulances and is widening the parameter around the emergency location to keep people at a distance. Parents that arrive at the scene, however, want to go to the restaurant.

Explosion - An unexpected explosion takes place on board of the ship. A police officer who was standing at the deck falls of the ship and into the water. He has to be pulled out as soon as possible. What happened to the fire service crew that was still in the ship is unclear. Another fire service crew is put together to explore the ship and see what has caused the explosion. It is unclear whether another explosion will follow so they have to enter with care, take measurements and carry protective clothing. When the crew checks the ship, they find that the explosion has been caused by an acetylene burner that was left on the ship. The engineer that has been carried off the ship was apparently working on something. When the burner is switched of and more windows are opened, the risk for another explosion disappears. The fire services find their colleagues in one of the ships compartments. Some of them have minor injuries. The explosion has started a small fire that is quickly extinguished.

Getting the situation under control - In the meantime, the police have found two more children in the surroundings of the ship. They are suffering from hypothermia and are directly handed over to the medical emergency services. The medical emergency services and the municipality try to figure out whether all children have been found now or whether there are still children missing. The police start their investigations in to the causes of the carbon monoxide leakage and the explosion. Because two people are found dead, an extensive investigation will take place. Soon, the municipality can confirm that all children have been found. Many of them have been transported to local hospitals and informing parents about the whereabouts of their children remains a challenge. The municipality is taking care of the remaining children, and takes care of the parents that arrive at the scene. The situation seems more or less stable and the police decides to scale down the closed area around the ship and let traffic at the canal resume.

The players: actors in the port carbon monoxide scenario

The port carbon monoxide scenario involves the same selection of core actors as the other exercise scenarios. The set of additional actors is different. The manager of the sailing school is an additional actor that forms a source of information to the emergency services. The manager has information regarding the technicalities of the ship as well as the number of victims that might be involved. The sailing school manager is also the source of information for the municipality as he has the credentials of the victims. The sailing school manager is role-played by the exercise staffs of the different emergency response actors involved in the exercise. The *KNRM*[6] liaison is the commander of the local rescue team that assist the fire services in the search for children that have fallen into the water. The *KNRM* liaison is only linked to the fire services and therefore role-played by the fire service exercise staff. The fire service commander is in charge of the search of the ship and the firefighting that has to be done after the explosion. The fire service commander is exclusively linked to the fire service officer and is role-played by the fire service exercise staff. The representative of the waterway operator can be alarmed to block off the port and the nearby canal during

[6] *Koninklijke Nederlandse Redding Maatschappij* (Royal Dutch Rescue Organization)

the emergency. This task is linked to the task of traffic management and the waterway liaison is therefore expected to coordinate his task with the police. The waterway liaison is role played by the police exercise staff. The core and additional actors involved in the port carbon monoxide scenario are listed in table 3.9.

Actor	**Appearance in the urban hazardous materials scenario**
Fire services	Present
Medical emergency services	Present
Police	Present
Municipality	Present
On-scene command team leader	Present
Information manager	Present
Sailing school manager	Role-played
KNRM liaison	Role-played
Fire service commander	Role-played
Waterway liaison	Role-played

Table 3.9- Emergency response actors in the port carbon monoxide scenario

The challenges: emergency response tasks in the port carbon monoxide scenario

The port carbon monoxide scenario involves ten tasks from the standard emergency management task list. There are seven tasks that qualify as monodisciplinary and three multidisciplinary tasks. The relatively limited number of multidisciplinary tasks is partly due to the specifics of the scenario and partly a result of the absence of the *KNRM* and waterway liaisons that are role-played by the exercise staff. The tasks in the port carbon monoxide scenario are listed in table 3.10.

Emergency response task	**Mono or multidisciplinary**	**Responsible actor(s)**
Firefighting and containing hazardous materials	Monodisciplinary process	Fire services
Rescue and technical assistance	Monodisciplinary process	Fire services
Measuring	Monodisciplinary process	Fire services
Medical care	Monodisciplinary process	Medical emergency services
Criminal / forensic investigation	Monodisciplinary process	Police
Undertaking	Monodisciplinary process	Municipality
Traffic management	Multidisciplinary process	Police, water liaison
Escorting	Multidisciplinary process	Police, medical emergency services, fire services
Registration	Multidisciplinary process	Municipality, medical emergency services, police
Shelter	Multidisciplinary process	Municipality, medical emergency services, police

Table 3.10 - Emergency response tasks in the port carbon monoxide scenario

The port carbon monoxide scenario presents an extensive set of monodisciplinary tasks. The seven monodisciplinary tasks include firefighting and containing hazardous materials, rescue and technical assistance, measuring, medical care, criminal investigation, traffic management, and undertaking.

Firefighting and containing hazardous materials consist mainly of the ventilation of the ship to remove carbon monoxide. Only in the immediate aftermath of the explosion, some firefighting tasks need to be performed. The firefighting and containing hazardous materials tasks is exclusively performed by the fire services. Rescue and technical assistance involves the rescue of victims from the ship and the search and rescue of those that have fallen into the water. The rescue is primarily a task of the fire services with some assistance of the local rescue team. Measuring is done by the fire services without assistance of an advisor on hazardous materials. Detection of carbon monoxide is relatively straight forward so the advisor on hazardous materials is not necessarily alarmed. The measuring starts as soon as the fire services arrive at the emergency location and lasts until the ship is pronounced to be safe. Medical care is provided by the medical emergency services and is initially exclusively oriented at the victims that have fallen into the water and suffer from hypothermia. After the explosion, the treatment of the firemen that are slightly injured is added to this process. The police has two monodisciplinary tasks to take care off: investigation and traffic management. With two people found dead on board of the ship, the investigation needs to be extensive and will be started as soon as possible. Traffic management is a less extensive task in the port carbon monoxide scenario. The police closes the local access roads to the port off and blocks the port for incoming ships in coordination with the waterway liaison. The last monodisciplinary task is taken care of by the municipality and involves undertaking. The bodies of the two deceased persons have to be removed from the ship and brought over to an undertaker.

One of the four multidisciplinary tasks in the port carbon monoxide scenario involves two emergency response actors, the other two are taken care of by multiple actors. Traffic management is performed by the police is cooperation with the waterway liaison. Escorting is done by the police if requested by the medical emergency services or the fire services. Because of the narrow access roads to the port, and the increasingly crowded area, escorting is required in the later stages of the exercise. Registration is a complex process in the port carbon monoxide scenario due to the initial absence of an overview of the number of victims involved in the emergency and the possibility that people have fallen into the water. The fact that the rescue and shelter operations are performed by multiple actors makes coordination more difficult. The process of registration includes the fire services that take care of the rescue, the medical emergency services that accommodate victims that have fallen into the water, the KNRM liaison that supports the rescue efforts, and the municipality that registers victims at the shelter location. The arrangement of shelter is done by the municipality, the medical emergency services and the police. Because of the extremely low temperatures, the on-site shelter is likely to be moved at some point in the exercise from the port to the restaurant to which the non-injured victims are brought.

The tasks in the Port CO scenario are divided over the initial, interim, and final stages of the scenario. Three initial process can be distinguished in the port carbon monoxide scenario: firefighting and containing hazardous materials, rescue and technical assistance, and measuring. All three tasks can start independently from other tasks, and right from the beginning of the exercise. The intermediate tasks are all related to the care of victims. Medical care and shelter aim at the accommodation of victims and are both dependent upon rescue. Registration is essential to keep track of the progress in the rescue efforts and takes place after medical care and shelter have been arranged. Traffic management and escorting are closely related and are also dependent upon rescue. The occurrence of an explosion halfway the exercise changes the emergency situation but has little consequences for the running emergency management tasks. The only tasks that are affected by the explosion are firefighting and containing hazardous materials and rescue. The firefighting and containing hazardous materials task becomes more intensive because of the fire. For this reason, the task is included as both an initial and an interim process. The rescue task is also intensified since the policeman that has fallen into the water needs to be rescued. The rescue task is therefore also approached as both an initial and an intermediate task. The final tasks in the port carbon monoxide scenario are investigation and undertaking. Both tasks are dependent upon firefighting and containing hazardous materials and measuring. The undertaking task is dependent upon the investigation as the bodies can only be removed after the investigation has taken place. The interdependencies between emergency response tasks in the ort carbon monoxide scenario are depicted in figure 3.9.

The need for coordination between the emergency response disciplines in the port carbon monoxide scenario exist mainly with regard to rescue operations. Given that victims are brought to the medical emergency services or the shelter location, a constant need exists to register the whereabouts of the victims. The processes of rescue, medical care, shelter, and registration are therefore linked. Successful management with the large group of victims requires coordination between the actors responsible for the four rescue related tasks. A second need for coordination exists with regard to the levels of carbon monoxide. Only when the carbon monoxide is removed, the police can start the investigation and the municipality the undertaking task. The fire services are responsible for the monitoring of carbon monoxide levels and coordination between the fire services and the other disciplines is essential for an effective emergency response. Other important moments for coordination can be expected with regard to the escorting task. Escorting requires coordination between the medical emergency services and the police. In contrast to the tasks described above, organizing escorts only requires bilateral coordination between two actors.

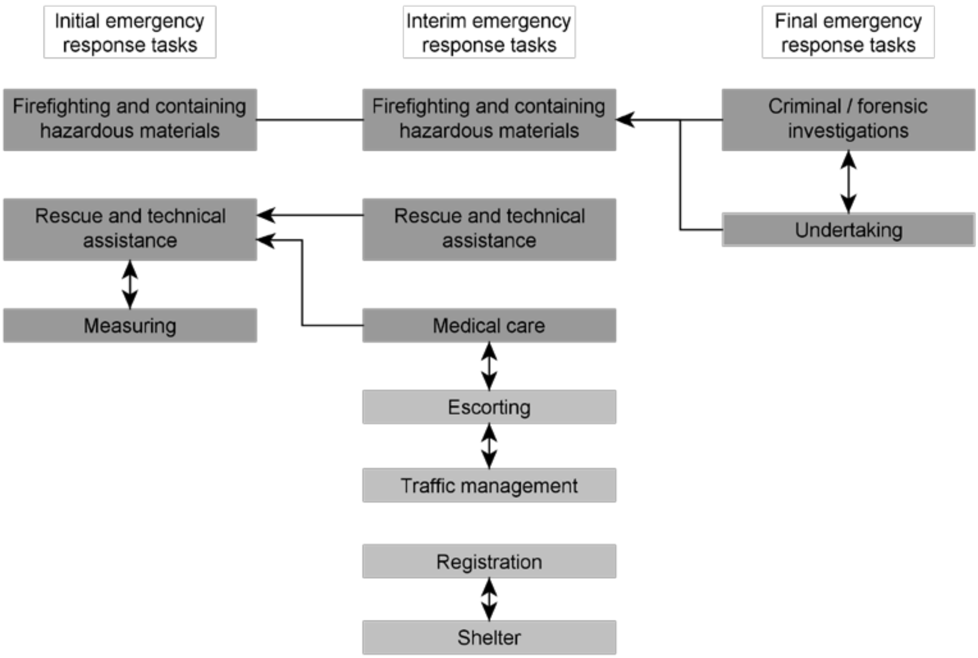


Figure 3.9 - Interdependencies between emergency response tasks in the port carbon monoxide scenario

A central role in the scenario is allocated to the fire services officer. The fire services coordinate the rescue operations and have to inform other services about carbon monoxide levels. A central and active role of the fire service officer seems therefore crucial for an effective emergency response. The task of rescuing and taking care of victims are the most comprehensive task in the emergency response. As these tasks are managed by various actors, the formation of a cluster around these specific tasks seems crucial for an effective response. Moreover, because the accurate registration of victims requires intensive information exchange, elaborate interaction between the actors involved is likely to be a prerequisite for emergency management performance.

3.6 Conclusion

We set out to explain how the important factors in the process of emergency response and emergency management performance can be studied during virtual reality exercises. Virtual reality environments provide a detailed and realistic setting for simulating emergency scenarios. Virtual reality exercises provide an opportunity for research because they allow researchers to observe emergency responders in action from a close distance and to repetitively study identical emergency scenarios. Because virtual reality technology makes it possible to develop exercise scenarios without the restriction of real-world settings, it allows exercise developers to include many interdependent and multidisciplinary response tasks that require multidisciplinary coordination. Moreover, the fact that virtual reality technology is particularly useful to simulate large scale, physical infrastructures makes virtual reality exercises a suitable setting for studying infrastructure recovery. These aspects make virtual reality exercises a useful setting to study processes of emergency response and emergency management performance.

Safety Region *Zeeland* uses virtual reality exercises as part of the preparation and training of emergency responders. The fact that Safety Region *Zeeland* organizes a permanent series of multidisciplinary virtual reality exercises that involve infrastructure operators makes the region a useful setting for this research. We presented and analyzed four exercise scenarios that form the basis for the empirical investigations.

Chapter 4
Study design

4.1 Introduction

To answer our research questions, we need an approach that fits the research setting of virtual reality exercises and enables us to study operational emergency management and performance. The central question in this chapter is: how can the important factors in the process of emergency response and emergency management performance be operationalized for empirical observation and comparative analysis?

Section 4.2 introduces the research strategy and explains how a combination of research methods is used to identify emergency management processes during virtual reality exercises. Section 4.3 outlines the research approach and explains how different research methods are combined to develop a rigorous and relevant account of operational emergency management. The operationalization of the analytical research framework – the important factors in the process of emergency response and emergency management performance – is presented in section 4.4. Section 4.5 describes the data collection process and section 4.6 presents the techniques used for data analysis.

4.2 Research strategy

The analytical framework presented in chapter two provides the initial conceptual structure on basis of which this study develops an empirical account of how operational emergency management performance comes about. The framework describes how to conceive of operational emergency management, i.e. what factors to study to explain variation in emergency management performance. The framework is not a full-grown theory of how operational emergency management performance comes about but rather a theory at the conceptual level. Moreover, the framework does not accommodate the specific characteristics of the multi-actor setting that characterize contemporary emergency management. The framework provides an initial structure that needs to be specified and filled up with more detailed descriptions of the actions and interactions of different actors to explain multi-actor emergency management. This section presents the research strategy – the research philosophy and methodological foundations – that is used to systematically gain in-depth understanding of operational emergency management.

Striving for rigor and relevance

Virtual reality exercises provide the setting in which we study operational emergency management. The closeness of the researcher to the research subjects makes it possible to gain detailed insights in the factors that drive operational emergency management performance. A detailed view of individual actions and organizational arrangements can thereby produce a practically relevant account. The repeating and identical settings created by virtual reality exercises enable a systematic comparison of operational emergency management. The close distance between the researcher and the research subject and the systematic comparison of similar situations makes it possible to perform a rigorous analysis. To aim to be relevant and rigorous at the same time sets requirements for the research strategy that are found in mixed methods research.

Mixed methods research

Mixed methods research (MMR) is often referred to as the third major research approach, besides the traditional qualitative and quantitative approaches. Mixed methods research can be defined as “the type of research in which a researcher or team of researchers combines elements of qualitative and quantitative research approaches (e.g. use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purpose of breadth and depth of understanding and corroboration” (Johnson, Onwuegbuzie, and Turner, 2007, p. 123) . This definition emphasizes the fact that mixed methods research is useful for both the understanding of phenomena as well as the corroboration of theoretical insights. The same point is stressed in earlier work of Johnson & Onwuegbuzie (2004) in which the authors state that the logic of inquiry of MMR enables both the development of theoretical insights and the testing of the validity of insights in different settings. It is the benefits for developing theoretical insights that this research is interested in.

The added value of mixing multiple methods for developing theory lies in the increased structuring of the analysis and the working with thin (reductionist or simplistic) and thick (complex and multidimensional) concepts (Coppedge, 1999). Qualitative research typically helps to develop thick, situationally relevant concepts while quantitative research aims at the applicability of thinner, more abstract concepts. Mixed methods research claims to obtain benefits for developing theory by switching between thin and thick conceptualizations of a phenomenon in order to increase understanding of the phenomenon. If working from thick to thin descriptions, researchers can find out whether the removal of variables from concept affects the value of an assertion and verify whether the thin description of a concept is the functional equivalent of its thick description. The same counts when working from thin to thick descriptions, when researchers can assess the effects of adding variables to a concept. The process of switching between thick and thin concepts is described by (Coppedge, 2009) as:

“These are major conceptual leaps that must be made carefully. We have to make sure that concepts that are used in one approach are the functional equivalents of concepts used in another approach if we are to get much benefit from combining approaches. This means that

as we climb the ladder of abstraction, we must leave behind the attributes that are irrelevant and take with us all the attributes that matter for the theory at hand. Unfortunately, knowing which attributes matter is hard. It requires round after round of theorizing and systematic testing" (p. 16)

Ahram (2009) has emphasized that the goal of mixing qualitative and quantitative methods is not "to amend qualitative and quantitative conceptual definitions until they are equivalent, but to identify their divergences" (p. 9). This is an important warning for this study. Understanding the differences between thin and thick conceptualizations of emergency management processes can help to understand emergency management performance. It is not our aim to develop universal definitions of these concepts that are simultaneously rich and specific enough to be measured. For example, the similarities and differences between a thin and thick definition of situational awareness can play an important part in understanding operational emergency management performance. A thin description of situational awareness might involve the observation that information is received by an emergency response actor and the amount of information that an actor has at its disposal. A thick description might include aspects like the choice of words that is used to exchange information between actors, the combination of different types of information, or the context in which information is exchanged. Knowing the differences between thick and thin conceptualizations helps to gain understanding in how operational emergency management performance comes about.

Structure of the analysis

Mixed methods research involves an intensive process of theorizing and testing that has benefits for developing theory. The MMR literature offers a set of strategies to structure this process. Efficient structuring is necessary to focus on relevant aspects in the large data sets that characterize qualitative research and to guarantee validity. Mixed methods research offers approaches to reduce time and improve the validity of an analysis by systematic and purposive sampling and selection of theoretically relevant cases. Case selection on basis of purposive sampling can help in assessing large amounts of data, explore the differences between thin and thick concepts, and thereby develop theory (Seawright & Gerring, 2008).

Purposive sampling is done by combining a quantitative with a qualitative approach. The quantitative approach is used to search systematically with quantitatively defined, thin concepts – for elements that matter – i.e. that are relevant for explaining variation in a phenomenon of interest. The qualitative approach is subsequently used to study these elements in depth, to provide empirically rich insights in how the phenomenon of interest comes about. In this study, this means that a quantitative approach is used to explore thin conceptualizations of emergency management processes like situational awareness and sensemaking, followed by a qualitative approach to study these processes in-depth to see how emergency management performance comes about.

Warranted assertions

Mixed methods research is useful to develop theory in a systemic way. However, the outcome of mixed methods research is often not 'theory' in the way it is commonly understood. Mixed methods research is rooted in the pragmatic research tradition that does not aspire theory in the sense of the pure knowledge of the positivist tradition (Boyles, 2006). Pragmatism emphasizes the provisionality of knowledge and the idea that all knowledge is dependent on the time and context in which it is produced. The insights obtained by pragmatists are therefore not formulated as theory but as warranted assertions (Shank, 2013). The insights do not form absolute knowledge that is independent from time and place but knowledge that is warranted by the specific inquiry from which it is derived. In line with this, pragmatists prefer the idea of 'knowing' over the idea of 'knowledge', as the later term indicates some static endpoint (Boyles, 2006). With exception of some elemental physical laws, situations always change over time and understanding specific situations is the highest possible aim of research according to pragmatism. This study uses the pragmatist perspective. The outcomes therefore consist of warranted assertions that are produced by the specific research setting.

Pragmatism as a philosophical foundation

Because mixed methods research and the pragmatic research philosophy are relatively uncommon, further explanation of the philosophical underpinnings of these approaches is provided. Besides using different research techniques and methodologies, quantitative and qualitative research departs from different research philosophies. Mixed methods researchers departs from an alternative philosophy, pragmatism. Pragmatism does not provide a fully developed 'paradigmatic' underpinning for scholarly research but three principles that are: aiming at real world problems, transactional realism, and holism (Johnson & Onwuegbuzie, 2004; Biesta, 2009; Shank, 2013).

The first principle, aiming at real world problems, is in line with our research strategy. A pragmatic research approach is a logical choice for this this research since the study originates from a set of practical and societally relevant problems. The recovery of infrastructure systems that are disrupted or damaged by incidents and variation in operational emergency management performance are real world, societally relevant problems.

The second principle of pragmatism, transactional realism, requires more explanation. Pragmatism positions itself in the middle ground between the two major paradigms in social science research: (post)positivism and subjectivism. Positivism is based on ontological realism and the assumption that objective truth can be established through scientific research methods. Subjectivism, on the other hand, rejects the conceptions of ontological realism and assumes that reality only exists in the way it is perceived and interpreted by individuals. In their pure forms, positivism and subjectivism present two incommensurable worldviews, with different ontologies, epistemologies, and generally a different use of methodologies (Biesta, 2010). To provide philosophical underpinnings for the combination of research methods, scholars have searched for alternative worldviews. This search has not aimed at the development of one of the approaches to overcome the issues it is struggling with but at finding a completely different approach. As stated by Biesta (2010), making a choice between the two traditional approaches is not the issue but "the far more important question is whether the underlying mind-world scheme is itself inevitable or whether it is possible to think about knowledge and reality in a different way, starting from different assumptions" (p. 106). One of the more developed and frequently applied alternative worldviews that has emerged is pragmatism and its ontology of transactional realism (Johnson & Onwuegbuzie, 2004). Transactional realism is different from objectivist and subjectivist ontologies and combines various aspects of the two approaches. Transactional realism is similar to subjectivism as it focuses on the experience of individuals. As stated by Garrison (1994), experience is central to the transactional perspective and comprises of everything that happens when people "actively participate in transactions with other natural existences" (p. 9). However, this experience is not something ethereal, happening in individual minds only, and therefore entirely subjective. In pragmatism, experience has ontological significance as it continuously shapes the world of which individuals are part. As stated by Biesta (2010), the essence of transactional realism is that "we are participants in an unfinished universe, rather than spectators of a finished universe" (p. 8). So the domain of knowledge and the domain of action are not separate but closely intertwined.

The epistemology of pragmatism is similar to that of subjectivism in the sense that it focuses on how the world is perceived or experienced. In this sense, pragmatism agrees with the subjectivist idea that "the social world can only be tackled from within" (Hollis, 1994, p. .142). However, according to pragmatists, these experiences are at the same time real and can be studied in the same way as objectivists study the world. This point has been explained by Biesta (2010) when discussing the work of John Dewey, one of the founders of pragmatism:

"For Dewey, knowledge always concerns the relationship between (our) actions and (their) consequences. This, in essence, is what a transactional conception of knowledge implies. It means that knowledge is a construction or, to be more precise, that the objects of knowledge are constructions. But contrary to how constructivism if often understood […](as purely mental and hence subjective), Dewey's constructivism is a transactional constructivism, a constructivism that holds that knowledge is at the very same time constructed and real." (p. 108).

Thus, epistemologically, a transactional conception of knowledge means that knowledge is simultaneously constructed and real. This has consequences for how knowledge can be obtained, i.e. how scientific inquiry is designed. Most importantly, the pragmatic approach holds that knowledge is obtained from studying the interaction between living entities with their environment and this interaction can be studied with qualitative as well as quantitative methods. In the context of our research, this means that operational emergency management can be understood by studying what emergency response actors say and do.

The third principle of pragmatism is holism. The principle of holism entails that events must be studied within their context. As stated by Shank, "events cannot be studied in isolation as they do not exist in isolation" (2013, p. 188). To understand social phenomena, they must be studied in the situation in which they originally occur, the situation that includes the transactions between the phenomenon of interest and its surroundings. Only when the transactional whole is integrated in a cohesive analysis process, understanding of social phenomena emerges (Shank, 2013). The isolation of social phenomena in the controlled, isolated setting of research laboratories does not result in relevant insights, according to pragmatists. Valuable insights can only be obtained from realistic settings. The virtual reality exercises introduced in the previous chapter provide a transactional whole of operational emergency management. Although virtual reality exercises are different from emergency management 'in the wild', they contain all the elements to provide a transactional whole of emergency response. All characteristics of an emergency situation are represented in the virtual environment, and all parts of the response organization are present of role-played by the exercise staff. Studying operational emergency management in virtual reality exercises does therefore support holism, the third principle of pragmatism.

4.3 Research approach

This study makes use of a multi-method, single-strand, conversion research design (Teddlie & Tashakkori, 2006). Although this description suggests differently, designing mixed methods research is not a matter of picking desired components from a menu. As stated by Maxwell & Loomis (2003), mixed methods research is opportunistic by nature and often involves an emergent strategy. Similar to qualitative research, mixed methods research follows up on insights that are gained during the research process. The design of this research has also evolved over time, starting off with a qualitative approach and adopting a quantitative approach and an iterative character as the research developed. The overall structure, however, can best be described as a multi-method, single-strand, conversion design. This section introduces the study design and describes the methods used for data collection and analysis.

Combining qualitative and quantitative methods

The combined use of quantitative and qualitative methods to answer the research questions makes that this study employs a multi-method research design. The initial and dominant method is qualitative video-ethnography. The details of video-ethnography and the way in which it is used for this study are described in section 4.4. In essence, video-ethnography provides an in-depth, thick description of the actions and interactions of emergency response actors and their relation to emergency management performance. The dominance of the qualitative approach results from the exploratory nature of the research and the absence of specific theoretical notions – as described in the previous chapter – which rules out the possibility of a deductive and explanatory research approach. The quantitative approach involves a communication network analysis. The communication network analysis is used to systematically explore the data and to select theoretically relevant focus areas, or cases for in-depth qualitative inquiry. The quantitative method should be seen as supportive, and therefore secondary to the qualitative approach. In mixed methods research design, quantitative approaches are generally labelled as 'QUAN' while qualitative approaches are pointed out as 'QUAL' (Creswell, 2008). If one method is dominant over another, the dominant method is referred to with uppercases and the subordinate method with lowercases (Teddlie & Tashakkori, 2006; Morse, 2010). In line with these conventions, the research design qualifies as a 'quan-QUAL' design (Creswell, 2008).

A research strand is defined as "a phase of a study that includes three stages: the conceptualization stage, the experiential stage(methodological/analytical), and the inferential stage" (Teddlie & Tashakkori, 2006, p. 16). This research employs a single-strand design. The analytical framework contains several concepts that potentially explain operational emergency management performance. All concepts are related and conceptualized in the first stage of the research. The concepts are individually analyzed and assessed during the experiential stage of the research that has both a qualitative and a qualitative component. After the analysis has finished, the outcomes are combined to discuss their individual and aggregate effects in the inferential stage. The fact that the analysis stage is strongly iterative can generate the impression of a multi-strand design since inferences are made and concepts are revised. However, since the overall design consists of a single strand, the research can best be qualified as a single-strand design.

Mixed methods research designs are traditionally characterized as either concurrent or sequential. Concurrent designs employ different methods simultaneously while sequential designs employ one method after the other. A less common option is a so-called conversion design, a design in which one type of data (either qualitative or quantitative) is collected at the data collection stage and subsequently conversed into another type of data during the experiential stage. A conversion design starts with a single data collection stage and can proceed with a concurrent or inferential experiential stage.

This research employs a conversion design. Qualitative, observational data is collected and conversed into quantitative, network data in the experiential stage. The experiential stage itself can best be qualified as sequential as the outcomes of the quantitative network analysis are used to inform and guide the qualitative assessment. The sequence of methods employed in a mixed methods research design is generally denoted with an arrow (→) (Creswell, 2008). According to these conventions, the research design can be described as:

‘quan → QUAL’

Mixed-methods research is strongly iterative, moving back and forth between the quantitative and qualitative approach to increase understanding of concepts and their relations. It is therefore more informative to speak of a conversion design than of a sequential design.

Purposive selection of ‘interesting’ cases

Different research methods provide different lenses (Garrison, 1994). The value of combining methods for developing theory lies in the possibility it offers to complement the weaknesses of individual methods and the insights that can be gained from switching between different lenses to look at a research problem. Mixed methods research develops theory by moving back and forth between thin, quantitative and thick, qualitative concepts and consequently develop and enhance theory. This moving back and forth can be done in a very structured as well as a more creative fashion (Coppedge, 2009). Since the aim of using a mixed-methods approach for this study is among others to increase the validity of the research findings, a structured approach that can be repeated and judged systematically is preferred. This research employs a structured integration of methods through purposive case selection techniques.

Case selection is an important and challenging aspect of social science research. Obviously, random selection forms the most powerful selection mechanism for making inferences since random selection allows a researcher to ignore other variables than the variables of interest and to generalize findings to the population from which a sample is drawn. However, random sampling can only be done when a large set of cases is available. Random sampling is an infeasible strategy in small sets of cases like the number of virtual reality exercises available for this study. When a small set of cases is available, purposive selection can be useful (Seawright & Gerring, 2008).

Purposive case selection involves the choice for appropriate cases for a certain research strategy. Appropriate in the sense that the cases are expected to be relevant and informative for the inquiry at hand. Purposive selection limits the possibility to generalize findings to a broader set of cases but increases the ability to study causal relationships (Mahoney & Goertz, 2004). The core criterion for purposefully selecting cases is variation on dimensions of theoretical interest. Seawright & Gerring (2008) distinguish seven methods to purposefully and systemically select and compare cases: negative, typical, diverse, extreme, deviant, influential, and most similar or different cases. What techniques to use depends on the data at hand, the research objective and research strategy. This study uses negative, diverse, deviant and most similar or different cases as a selection method for comparing cases. The use of typical, influential, or extreme cases is omitted because the data set is too small to determine whether a case is typical for, or of significant influence on relations found in the larger data set. Table 4.1 gives an overview of case selection methods.

Case selection method	Description
Negative cases	The selection of a (set of) negative case(s) is useful to test a theory. Negative case selection relates closely to the possibility principle that is used to determine the relevance of cases (Mahoney & Goertz, 2004; Seawright & Gerring, 2008). For a negative case to be informative, it must first be determined to be relevant. This requires a more in-depth assessment of the case. If the case is relevant, i.e. the outcome could have occurred, negative values on variables of interest form a reason to reject a hypothesis, to refine indicators, or to draft new hypothesis.
Diverse cases	An assessment of diverse cases requires the selection of two cases that represent the full range of values characterizing the variation of variables of interest (X, Y), or some particular X/Y relationship. To explore a relationship, it is useful to look at the values of the variables (X, Y). To explain a relationship, it is necessary to look at the relation between different variables (X/Y) (Seawright & Gerring, 2008).
Deviant cases	A deviant case is an anomaly, a score on theoretically relevant variables that is difficult to explain from the general model of causal relationships (the working hypotheses). The value of an in-depth study of deviant cases is to probe for new, yet not specified, explanations. A deviant case, for example, can be used to disconfirm relationships that are commonly assumed to be in place (Morse, 2010).
Most similar / most different cases	An in-depth study of sets of most similar or most different cases is useful to see whether an expected causal mechanism is really in place (are similar cases really similar?) or to derive new hypotheses. In the purest form of the most similar / different method, the values of all measured independent variables are similar except for the independent variable of interest. If only one independent variable varies, it is this variable that causes variation of the dependent variable. However, as values are often not that perfectly distributed, the application of theoretically informed threshold levels will often be necessary. The selection of most similar or different cases can be done with various matching techniques, from exact matching to approximate matching methods (Creswell, 2008).

Table 4.1 - Techniques for purposive case selection

Research steps

This empirical part of this research consists of two phases that each involve three analytical steps. The first phase involves the 'quan' part of the research and is used to quantitatively analyze the characteristics of the communication networks between emergency response actors. The outcomes of this analysis are used to select parts of the emergency responses as focus cases for the second 'QUAL' phase of the research. These focus cases can be the actions and interactions of individual emergency response actors, groups of actors, or complete on-scene command teams as well as specific moments or events in an emergency response that require further, in-depth study. The selection of focus cases takes place with the methods for purposive selection described in the previous section. Further on in this chapter, an overview of communication network analysis metrics is provided and discussed in relation to emergency response processes and the analytical framework of operational emergency management performance. This discussion results in a collection of working hypotheses about the relation between communication network characteristics as indicators of emergency response processes and operational emergency management performance. These are the 'variables of interest' in this study. The working hypotheses and the purposive selection methods provide a guideline for the empirical case study work.

The aim of the 'quan' phase is to systematically explore the data for overall relations and areas of interest for further, in-depth inquiry. The first analytical step of the quantitative phase of the empirical analysis is to see whether the working hypotheses are supported by the collected data. Does the hypothesized relation between emergency response processes and emergency management performance exist in the data? When support for a working hypothesis is found, most different and diverse cases on the variables of interest are selected for in-depth inspection in the QUAL phase to see whether the expected causal mechanisms are really in place. The data is also checked for negative or deviant cases that are forwarded to the QUAL phase as well to find out why the relation does not occur in all cases. The second step of the quantitative phase is taken when a working hypothesis is not supported by the data. In this situation, the data is explored to see whether a different relation is found between the variables of interest, i.e. emergency response processes and emergency management performance. If an alternative relation is found, most different and diverse cases as well as negative or deviant cases are again selected for further, in-depth inquiry. When no relation at all is found with regard to a working hypothesis, the third analytical step is taken. The third step involves a check for correlations between communication network metrics and emergency management performance that have not been part of the working hypotheses. If a relation is found, most different and diverse cases are selected for in-depth inquiry to explore the causal mechanisms in the relation. When no (more) relations are found in the data, the 'quan' phase ends.

The aim of the QUAL phase is to trace the causal mechanisms behind the relations found in the 'quan' phase. The first step of the QUAL phase is to explore whether the explanations from the analytical framework of operational emergency management performance can indeed be found in the supported working hypotheses. This means for example that, when a relation between situational awareness and emergency response actors' performance is found, the actions and interactions of both the highest and lowest performing actors are studied to see whether the high performing actor was indeed situationally aware while the low performing actor was not. When the mechanism is found in the most different cases, diverse cases are added to provide additional empirical insight in how the processes observed contribute to emergency management performance. When the mechanism is not found, negative cases and extremes on the variables of interest are added to the selection of focus cases to search for alternative explanations. Continuing with the example above, this would imply that cases in which an emergency response actor scores high on situational awareness but performs poorly, or an actor that scores low on situational awareness but performs well are included as well. When an alternative explanation is found, it is subsequently used to see whether it can explain the overall relation that was found in in the data in support of the working hypothesis. The second step of the QUAL phase is to explore the relations that emerged in the quantitative communication network analysis and that were not part of a working hypothesis. In these situations, the most different and diverse cases are studied to see what actions and interactions of the emergency response actors involved cause the relation detected in the data. The third step of the QUAL phase is to study parts of the emergency response that have not been part of the quantitative network analysis. Since this includes the meetings of on-scene command teams, this is a considerable part of the emergency response. The third step of the QUAL phase is therefore the largest component of the qualitative research.

In essence, the research consists of two consecutive phases, but the practice of data exploration and analysis is highly iterative. The outcomes of the second, QUAL phase have also been fed back to the network analysis to see whether the qualitative findings could be related to broader trends in the network data. The research is characterized and presented as having a two phase approach for conceptual clarity, but the practice of mixed methods research is – as stated by (Coppedge, 2009) – mostly a matter of going back and forth between methods and thin and thick conceptualizations of phenomena of interest.

4.4 Operationalization

As a mixed methods study, this research employs qualitative and quantitative methods to study the emergency management processes of our analytical framework. We use network analysis to analyze emergency response communication and video-observations to study emergency response in depth. Whereas emergency management processes can be observed more or less directly through video-observations, the indicators created by network metrics must be interpreted in the context of emergency management processes before the analysis can be done. We use this section to explain how emergency management processes and emergency management performance are operationalized through communication network analysis, video-observations and a performance assessment method.

The first part of this section (4.4.1) explains how we use network analysis as a quantitative method to analyze situational awareness, emergent coordination, and collective sensemaking by emergency response actors in the field. Section 4.4.2 presents video-ethnography as a method to study emergency management processes in depth. Video-ethnography is used to study collective sensemaking and emergency decision-making during on-scene command team meetings and to verify and thicken insights in situational awareness and emergent coordination in the field. Section 4.4.3 explains how we use task scores to assess operational emergency management performance and self-assessment during exercise evaluations as a validity check.

4.4.1 Communication network analysis and emergency management processes

Communication networks provide a concrete and comprehensive image of emergency response organizations. Communication networks reflect actions and interactions and indicate which emergency response actors played a prominent role and which actors stood aloof during an emergency response. Communication network analysis is systematic and specific and provides a rigorous way to analyze emergency response organizations. This section describes how communication network analysis is used to analyze operational emergency management processes in virtual reality exercises.

Tracing situational awareness and emergent coordination with network metrics

Actors that have structurally advantageous positions within a network tend to receive benefits in terms of information and control (Burt, 1992). Information and control are key factors in emergency management. Returning to the analytical framework of chapter two, information is at the core of situational awareness and control at the core of emergent coordination. This section presents how the structural positions of emergency response actors in communication networks can be linked to increased performance through situational awareness and emergent coordination.

Situational awareness is about the continuous extraction of information from the environment and the development and maintenance of an accurate understanding of an emergency situation. To maintain their situational awareness, emergency response actors need to collect and verify information continuously. Emergency response actors obtain information by performing a situational assessment at the incident scene and by obtaining information from other actors. The exchange of information with other actors is not only important to obtain information but also to verify the correctness of information. The overview of individual emergency response actors of an emergency situation is often limited and comparison and verification of information is necessary to create a complete and reliable operational picture.

Previous network analysis research in other settings than emergency management has shown that actors that have structurally advantageous positions within a network tend to outperform others (Burt, 1982, 1992). What structural position is advantageous depends on task that is performed and the conditions under which a task is performed (Schulz, 1998; Mehra *et al.*, 2006). An appropriate and effective emergency response can only be developed on basis of a correct operational picture. Situational awareness is therefore crucial for emergency management performance. Actors continuously need information to perform well. Emergency response actors need to have a good position in the emergency response communication network to obtain and verify information from other actors.

Increased situational awareness is why centrality in a communication network is expected to have a positive effect on actor performance.

Emergent coordination is about the control of individual actors over the emergency response organization. The majority of research into the effects of network structural positions for control is concerned with the position of team leaders. Key questions in this field are whether formal team leaders must be central in a team's network to increase performance or whether informal leaders can be detected in team network structures (Mehra *et al.*, 2006). The benefits that actors receive from their structural position in terms of control are believed to stem from the more comprehensive view that can be obtained while occupying a central position in a network. This overview causes actors to make better decisions and allows them to act as regulators or gatekeepers of resource flows (Chwe, 2000). The advantageous positions in a network have also been described as opportunity structures that facilitate and constrain action (Schulz, 1998). Leaders at structurally advantageous positions are believed to benefit from their abundant connections with team members and team leader centrality is shown to be positively associated with team performance (Balkundi & Kilduff, 2006). A specific branch of this research is concerned with leader-member-exchange (LMX) in teams (Dionne *et al.*, 2010). This research shows that horizontal information exchange between emergency response actors has a positive effect on team performance when actors have heterogeneous expertise or strong mutual interest. When actors have homogeneous expertise or weak mutual interest, leader member exchange increases performance (Carson, Tesluk, and Marrone, 2007; Dionne *et al.*, 2010).

Formal leadership is weak in operational emergency management. On-scene command team meetings are headed by a team leader but the overall operational response is characterized by horizontal coordination between independent emergency response organizations. It is therefore of limited use to focus on the position of the formal leader, and more useful to focus on actors that take up a leading role in the emergency response. In the network like structure in which operational emergency response is organized, all emergency response actors have to take the lead with regard to some emergency response tasks and have to become informal leaders if the situation requires so. That is what emergent coordination is about. Emergent coordination involves processes like situational assessment, deciding on goals and a course of action, division of tasks, and the orchestration of parallel and interdependent tasks. These processes involve communication between emergency response actors. Performing emergency response tasks requires emergent coordination and emergent coordination requires communication. This is why having a central position in the emergency response communication network is expected to make a positive contribution to actor performance.

Both situational awareness and emergent coordination make a positive contribution to emergency response actor performance and can be linked to a central position in emergency response communication networks. This relation is expressed in the first hypothesis that is used to guide the empirical research:

Hypothesis one: The centrality of emergency response actors in emergency response communication networks is positively associated with actor performance.

Besides the general relation between actor centrality and performance it is possible to hypothesize up front at what moment(s) of emergency response a structural advantageous position in the emergency response communication network is most important. Situational awareness is always important and requires continuous updates. However, developing an accurate operational picture is most urgent and challenging during the early stages of emergency response when little is known or certain about an emergency situation. During later stages of the response, the operational picture is already available but needs to be updated. The development of an operational picture requires more communication than updating it. Communication with other emergency response actors is therefore expected to be more important in early stages of emergency response than later stages. A similar reasoning can be done for emergent coordination. The orchestration of tasks is important throughout the entire emergency response but situational assessment and deciding on goals and a course of action are most prominent in the early stages of the response. Because situational awareness and emergent coordination are both most important at the early stages of emergency response, the centrality of emergency actors is also expected to make the strongest contribution to actor performance in the early stage of emergency response:

Hypothesis two: The centrality of emergency response actors in emergency response communication networks during the early stages of emergency response, and decreasing centrality in later stages of the response, are positively associated with actor performance.

The position of emergency response actors is assessed with all five centrality metrics presented in the previous section to answer this question. Degree, betweenness, closeness, eigenvector, and weighted-degree centrality do all provide an indicator of an actor's position. For all metrics counts that, the higher the value, the more central the actor is positioned within the network. It is difficult to gauge beforehand how the centrality of actors, as indicated by the different centrality metrics, relates to actor performance. It is part of the exploratory nature of this research to leave this open to use multiple centrality metrics to find out if, and what structural positions are advantageous for emergency response actors.

Clusters as indicators of emergent coordination of multidisciplinary tasks

Being central in the emergency response communication network is expected to make a positive contribution to emergency response actors because it increases their ability to perform their monodisciplinary tasks. Multidisciplinary tasks are performed by multiple actors and can therefore not be linked to the centrality of a single actor. Emergent coordination of multidisciplinary tasks requires multiple actors to cooperatively perform a situational assessment, decide on goals, and distribute tasks. To analyze how multidisciplinary tasks are coordinated, it is useful to look at subgroups of multiple actors within emergency response communication networks.

Network analysis offers ways to analyze the extent to which emergency response actors group together and form clusters within a team. Emergent coordination of multidisciplinary tasks requires communication between multiple emergency response actors and the formation of clusters within the communication networks is therefore a prerequisite for coordination. The relation between communication in clusters and multidisciplinary task performance is similar to the relation between actor centrality and actor performance. More communication in subgroups is expected to be associated with more coordination, and hence better performance.

The positive relation between communication in subgroups and multidisciplinary task performance is primarily expected during later stages of emergency response. In initial stages, multidisciplinary tasks are limited and communication is likely to be abundant between all actors involved in the emergency response. As many communicate with each other, subgroups are difficult or impossible to distinguish. During later stages, communication becomes more focused on multidisciplinary tasks and subgroup formation becomes a useful indicator of the extent to which communication within the intra-team network clusters around specific tasks. This relation is expressed in the following hypothesis:

Hypothesis three: The tendency of emergency response actors to communicate in subgroups in later stages of an emergency response is positively associated with emergency management performance regarding multidisciplinary tasks.

The formation is subgroups within a communication network can be measured with the clustering coefficient that indicates the number of closed triplets within a network. A closed triplet indicates three emergency response actors that communicate with each other. Because triplets involve more than two actors, they only apply to multidisciplinary response tasks that involve more than two disciplines. The generalized clustering coefficient does also incorporate the duration of the interaction between the actors. The clustering coefficient and generalized clustering coefficient are used to analyze the tendency of emergency response actors to communicate in subgroups during the course of an emergency response.

Structural network metrics that indicate collective sensemaking

Balkundi & Harrison (2006), stated that "the patterns of informal connections (ties) among individuals, can have important implications for teams because they have the potential to facilitate and constrain the flow of resources between and within teams" (p. 49). The flow of information between emergency response actors is crucial for emergency management performance. Information exchange is not only necessary to fuel individual situational awareness, but also to facilitate a process of collective sensemaking. As explained in chapter two, collective sensemaking is about collecting and sharing information as well as processing and making sense of information. These latter aspects – collective processing and sensemaking – take place during on-scene command team meetings and cannot be analyzed with communication network metrics. The first aspects – collecting and sharing information – can.

The general measure of network structure is network density. The density of emergency response communication networks indicates the proportion of emergency response actors that communicate with each other and, in case of weighted density, the duration of their communication. Measuring the density of emergency response communication networks provides insights in how information is exchanged between emergency response actors. Network analysis research has an elaborate track record of showing how information is dispersed through communication networks. The most comprehensive work on network analysis in team research is that of Balkundi & Harrison (2006) who present a meta-review of 37 studies that relate team network characteristics with team performance. Their review indicates that densely connected teams share more information and are better at attaining their goals. Similar outcomes have been obtained from research on the dissemination of information in teams (Borgatti & Foster, 2003; Brass *et al.*, 2004). Related research has focused on the consequences of structural holes for organizational performance. Structural holes are the gaps that exist when two nodes in a network are not connected (Burt, 2001). When studying the effects of structural holes in organizational networks, researchers found that structural diversity matters for organizational performance as low structural diversity (few structural holes) is associated with a lack of new ideas rising in an organization (Balkundi *et al.*, 2007). This insight seems closely related to observations on groupthink in isolated and closely knit teams (Janis, 1982). On the other hand, researchers found that organizations with high structural diversity (many structural holes) are associated with coordination problems (Balkundi *et al.*, 2007).

The first part of collective sensemaking requires information to be exchanged between emergency response actors so that all actors have the same operational picture. For all emergency response actors to establish the same operational picture requires communication between all emergency response actors. The amount of communication within a network can be measured with network density. Because operational emergency management is strongly dependent on information, the positive relation found between network density and performance in previous research is also expected to exist for emergency response communication networks. Dense networks indicate abundant information exchange and the development of a basis for collective sensemaking. Since collective sensemaking is a necessary part of emergency management, dense communication contributes indirectly to operational emergency management performance. This relation is expressed in the following hypothesis:

Hypothesis four: The density of emergency response communication networks is positively associated with emergency management performance.

In addition to the general relation between the amount of communication and operational emergency management performance, time is expected to be a factor of influence. Previous research has indicated that time plays an important role in the relation between network characteristics and performance. Sheard & Kakabadse (2007) studied team network characteristics during phases of team formation (forming, norming, storming and performing (Tuckman & Jensen, 1977)) and found a correlation between density and performance. However, the outcomes of this research are inconclusive on whether team integration precedes performance or vice versa. The initial stage of emergency response is characterized by the situational assessment and the development of a common operational picture. These initial processes require intensive communication between emergency response actors. In later stages when emergency response tasks have started, communication can be limited to situational updates and the coordination of response tasks. The density of communication between emergency response actors is therefore expected to be most important during the initial stages of emergency response. This relation is expressed in the following hypothesis:

Hypothesis five: The density of emergency response communication networks during the early stages of emergency response, and decreasing density in later stages of the response, are positively associated with emergency management performance.

Two metrics are used to measure the density of communication networks. Communication network density indicates the proportion of emergency response actors that interact with one another. In its basic form, density does not include the duration of communication. This makes density ill-suited to analyze the amount of communication that goes on between emergency response actors. However, since density provides an intuitive measure of integration that is easy to calculate, it will be applied to see whether and how it relates to emergency management performance. Weighted density does include the duration of communication and provides a better indicator of the amount of communication between emergency response actors. Weighted density includes the number of connections within an emergency response communication network, and the duration of these connections, as a proportion of the maximum possible number of connections and their maximum duration. Density and weighted density are used to analyze the amount of communication during emergency response.

4.4.2 Video-ethnography of emergency management processes

Communication network analysis provides systematic insights in how structural features of the emergency response organization relate to emergency response processes and emergency management performance. Communication network analysis does not explain how emergency management performance comes about. To understand the mechanisms through which emergency management performance comes about (or not), a qualitative, observational approach is used to develop an in-depth, empirical account of emergency response processes. The account fills up the analytical framework of chapter two with descriptive detail of how emergency management performance comes about in practice. A thick description that allows a variety of concepts to play a role is necessary to provide relevant insights about the organizational setting of multidisciplinary emergency response (Denzin & Lincoln, 2005). The outcomes of the network analysis and the outcomes of the performance assessment provide a range of indicators from which theoretically relevant focus cases are selected. The focus cases are further explored using a video-ethnographic approach. This section describes the video-ethnographic approach and explains how observations are analyzed and combined to develop theoretically relevant insights.

Video-observations

The video-ethnography was structured along the four emergency response processes that are part of the analytical framework presented in chapter two. The observations started by focusing on situational awareness and emergent coordination in the field and continued with collective sensemaking and emergency decision-making during on-scene command team meetings. The accounts of situational awareness, emergent coordination, and collective sensemaking were developed on basis of the focus cases selected from the performance assessment and communication network analysis. The account of emergency decision-making has been developed on basis of the focus cases from the performance assessment and observations alone because the process could not be analyzed with communication network metrics.

The development of video-ethnographic accounts was done with an observation protocol. The overall outline of the protocol is based on three main-questions for each emergency response process in the analytical framework: What actions did the actors take to perform the emergency response process? What interactions took place between actors with regard to the emergency response process? What, if any, events influenced the performance of the emergency response process? More detailed questions were added for each emergency process on basis of the specific characteristics of the concept. For emergent coordination, for example, it was also asked what actors did to distribute tasks or to decide upon a course of action. When the development of the ethnographic account progressed, more questions were added to track actions, interactions, or events that turned out to be influential in the focus cases. Because of the continuous addition of observed concepts, the ethnographic accounts expanded quickly, starting with a set of core questions and growing to a comprehensive web of related concepts.

The development of the ethnographic accounts was structured through the pairwise comparison of focus cases (Onwuegbuzie & Leech, 2007). The analysis of emergency decision-making, for example, started with the comparison of the highest and lowest performing team in the Urban hazardous materials scenario. These cases were selected because of the variation in performance and the fact that the scenario contains some specifically difficult decisions about evacuation and the safety of emergency responders. Relevant video footage was collected for each focus case and a verbatim transcript was made of the conversations involved. The video clips and transcripts were subsequently coded with regard to concepts relating to the emergency response processes from the analytical framework. This is a form of selective coding – in contrast to open coding – since the initial codes are derived from theory instead of the initial observations (Strauss & Corbin, 1990). When the analysis of video clips and transcripts progressed and the understanding of emergency response processes advanced, coding labels were changed, removed, added, and related. This process increased the theoretical depth of the account and generated insights beyond the initial analytical framework. The video-ethnography resulted in four accounts of emergency response processes that help to explain how operational emergency management performance comes about in a multi-actor setting. The accounts consist of a great number of empirical concepts – actions, interactions, and events – that influence operational emergency management performance. These concepts are rather loosely defined and remain close to the terms used by the emergency responders and the labels used in the coding process (Spencer & Britain, 2003).

4.4.3 Assessing emergency management performance

Operational emergency management performance can be assessed in different ways. This study uses a task and outcome oriented approach. The reason to focus on tasks and outcomes is that we are interested in how successfully different aspects of an emergency are managed and, more specifically, why the recovery of infrastructure functions is managed more effectively in some cases than others. This requires a focus on observable outcomes and not on factors like emergency response actor satisfaction or peer-judgments. This section introduces the method that is used to assess emergency management performance and the measures that are taken to ensure the validity of the assessment.

Task scores

To focus on tasks and outcomes, a scoring method for emergency management performance is developed. Operational emergency management performance can be analyzed in terms of processes and outcomes. Emergency response tasks involve a process that, if completed successfully, results in a certain outcome. For example, the rescuing of victims requires the localization of victims by the combined emergency services, the actual rescuing of victims by the fire services and the medical emergency services, and the transport of victims to shelters or hospitals by the medical emergency services and local municipalities. The task can be separated in a process and an outcome. The process includes the localization, rescue, and transport of victims and the outcome is the number of victims that are delivered to the right location, either a shelter or a hospital.

Outcome scores are at the core of the scoring method for emergency management performance in this study. When an emergency response task is finished, a fixed outcome score is provided. A pure outcome oriented approach would focus on the outcomes alone and leave the processes for what they are. Such an approach is insensitive to the extent in which a task is completed and the effort that is spend by an emergency response actor to complete a task. This is undesirable for assessing operational emergency management performance because tasks can be complex and processes do not always lead to outcomes in a straightforward manner. To accommodate this complexity, a task score is provided as well when an emergency response process is being executed but has not yet finished (completely). To take the difference between a running task and a completely finished task into account, the score for a running task is lower (score = 1) than the score of a task that has finished (score = 2). The scoring method can be illustrated with the example above. From the moment that emergency response actors start localizing and rescuing victims, a score of 1 is provided. Once that all victims have been localized and transported to a shelter or hospital, the task is completed and a score of 2 is provided.

Time is a key factor in emergency response. The sooner that emergency response tasks are started and finished, the better. To include the timing of response tasks in the scoring method, scores are provided during each phase of an emergency response. A phase is either an action episode – an emergency response in the field – or a transition episode – an on-scene command team meeting (see chapter two). The scores obtained at each phase of an emergency response are accumulated to derive at a final, overall score. This implies that the sooner an emergency response tasks is started and finished, the higher the final score. The example above is again used to illustrate the scoring method. As soon as the process of localizing victims is started by one of the emergency services, a score of 1 is provided. A score of 1 is provided each time that a new phase starts for as long as the emergency response actors keep working on the rescuing of victims. Once that the response task is finished, a score of 2 is given. A score of 2 is given again for each remaining phase. When a team starts and finishes a process right in the first phase of the emergency response, a score of 2 is provided from the beginning of the exercise and again for each following phase. Since the exercises involved three phases of response in the field and three on-scene command team meetings, the maximum score that could be obtained for an emergency response task was 12.

A score is kept for every emergency response task that is part of an exercise scenario (see the scenario descriptions in chapter three). The scores are subsequently plotted on a radar chart to give an overview of the distribution and overall performance for a given exercise. The setup of a radar chart is shown in figure 4. The diagram has an emergency response task on each axis and the scores of a fictitious team are shown as an example.

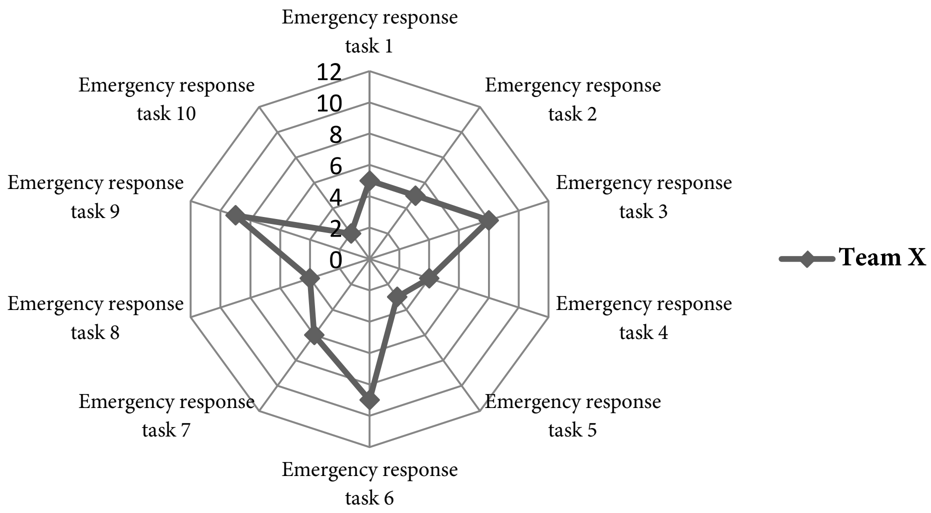


Figure 4 - Emergency management task scores radar chart

Emergency management task scores can only be compared for the same tasks in the same exercise scenarios or after normalization. The final, overall score that can be obtained for an emergency response task depends on the characteristics of the task and specifics of the emergency scenario. When an exercise scenario involves fire, for example, the criminal and forensic investigations task can only start when firefighting has been finished. The maximum score of criminal and forensic investigation is therefore not 12 but lower, depending on the moment in the exercise scenario when the criminal or forensic investigation task can start. These differences, and the fact that some emergency management tasks are more complex than others, make that the performance scores of different emergency response tasks cannot be compared. A comparison can only be made between similar processes that take place in similar or comparable scenarios. The performance scores are therefore only used to compare similar emergency response actors that participate in the same exercise scenario. Comparison between performance scores is enabled by normalizing the performance scores for the range of comparable actors that took place in the same exercise scenario. In this way, the performance is not judged in an absolute sense, but relative to other actors that took part in the same exercise scenario.

Emergency management task scores make it possible to generate a multilevel performance assessment. Operational emergency management performance is assessed on four levels: individual emergency response tasks, individual emergency response actors, multidisciplinary subgroups, and on-scene command teams as a whole. The section above describes how scores are provided for individual emergency response tasks. These scores form the building blocks to assess performance at higher levels. The performance of individual emergency response actors is assessed by adding the scores of all emergency response tasks for which an emergency response actor is responsible. The performance of multidisciplinary subgroups is based on the emergency management task score of the task for which the subgroup is responsible. The performance of on-scene command teams is based on the combined scores of all emergency response tasks that are part of an exercise scenario. The four levels of the performance assessment are shown in table 4.5.

Performance indicator	Operationalization
Task performance	Performance with regard to an individual emergency response task, established with a score of 1 when a task is being executed and a score of 2 when a task is completed. Scores are given in each emergency response phase.
Actor performance	Performance of an individual emergency response actor, established by adding the scores of all emergency response tasks for which an actor is responsible.
Multidisciplinary subgroup performance	Performance of a multidisciplinary subgroup, based on the task performance of the task for which the subgroup is responsible.
On-scene command team performance	Performance of an on-scene command team, established by adding the scores of all emergency response tasks for which an on-scene command team is responsible, i.e. that are part of an exercise scenario.

Table 4.5 - Emergency management performance levels

Validity checks

A comprehensive assessment of emergency management performance requires a thick-description of the emergency response in each individual exercise observed. Such a thick-description would do justice to the complexity of emergency response tasks but makes it difficult to compare performance scores. The scoring method simplifies task performance with a process and outcome score and thereby create a comparable and objective performance measure. However, the simplification removes much detail and contextual information from the performance assessment. By omitting such details, crucial information on how a process was executed or how a certain outcome is established, is removed. Simplification comes with the risk that outcomes cannot be explained without details that have been removed or that people involved have a different perception of the process than what is reflected in the objective measure. The measure might indicate poor performance while the emergency responders involved are positive about their performance or vice versa.

To verify the validity of the task scores – and the performance assessment – two forms of control are used. First, the task score is compared to the score provided in the post-exercise questionnaire for the question "how well did you perform during the exercise?". The answer to this question comes on a 5 point Likert-scale. Second, the post-exercise evaluations are used as a qualitative control for face validity. To reduce the risk of over-simplification or omission of crucial details, the post exercise evaluations are used as a check for the performance assessment. If specific factors played a role during the execution of emergency management tasks or outcomes could not be established due to specific circumstances, these issues come up during post-exercise evaluations. When the performance measure and the post-exercise evaluation diverge strongly, a more in-depth study of the exercise is made to see why the assessment and evaluation deviate. The post-exercise evaluation is also used to provide details and contextual information when an exercise is selected as a focus case (see section 4.3).

4.5 Data collection

The primary methods for data collection during the exercises were video and participant observation. All exercises have been recorded on video from five different positions. One camera was placed in the coordination room in which the on-scene command team meetings took place. Four cameras were placed in the field room (see figure 3.1 in chapter three). The cameras in the field room were aimed at the positions of the actors involved in the emergency response. The five cameras combined were able to capture all interactions that took place in the exercises. The camera in the coordination room was also used to record the briefings of the exercise staff, the briefing of the participants, and the post-exercise evaluations. Recordings were started at the same moment and the cameras were time-synchronized to facilitate the exact tracking of interactions between actors. The researcher was present during all exercises and took elaborate field notes. Being present during the preparations of the exercises, the briefings, intermediate breaks, and lunches allowed the researcher to collect additional information on specific aspects of the exercise scenarios and the actions and attitudes of emergency response actors. The combination of observations and casual talks with the participants proved particularly useful to explain unexpected actions or interactions in the exercises. The presence and time available at the exercise location provided the researcher with the opportunity to ask participants why they acted in a certain way if this could not be explained from the scenario or the evaluations. The outcomes of these conversations were written down in field-notes during and directly after each exercise.

Post-exercise questionnaires were used to gather information about the participants and to ask questions about the exercises. The questionnaires were handed to the participants after the post-exercise evaluation had finished. The questionnaires were distributed together with an exercise evaluation by the Safety Region. It took the participants approximately fifteen minutes to fill in both questionnaires. The items on the questionnaire were adjusted once after the first two exercises because some questions proved to be difficult to answer for the participants.

During the exercises, an observation-log was used to track differences between the exercises. For every exercise, the participants, exercise staff, and visitors or observers were registered. The observation-log included the exact time of the start of the exercise and the end-time. The observation-log also included whether participants participated for a second time in the same exercise scenario (which happened once) and whether they had participated in one of the other virtual reality exercises (which happened six times). The observation-log was further used to register whether (technical) problems were encountered during the exercises.

The exercise scenario descriptions provided a comprehensive and structure overview of the events that were part of each exercise. To gain insight in the background of each scenario, we analyzed various additional documents. These documents included the emergency response plan of Safety Region *Zeeland*, the *Westerschelde Tunnel* emergency response plan, the guidelines of the Safety Region *Zeeland* for crisis communication, and guidelines on the management of hazardous materials.

Data processing

The observations resulted in field notes, questionnaire outcomes, and approximately 350 hours of video footage. The observational data collected during the exercises was converted into relational data to enable communication network analysis (explained in the next section). This was done by registering the interactions between emergency response actors. For each interaction, it was registered which actor initiated the interaction, at which actor the interaction was aimed, the exact time at which the interaction started, and the exact time at which the interaction ended. The registration was done in a spreadsheet (.xls - Excel file) in which the data could be processed in different formats. The relational data was subsequently saved in a comma separated format (.csv) to serve as input for several network analysis software packages.

The richness of the relational data required that several network analysis software packages were needed to generate network metrics and to create network visualizations. Basic network metrics were calculated with UCINET (Borgatti, Everett, and Freeman, 2002). Several weighted network metrics that could not be calculated with UCINET were calculated with R in the ‘sna’ and ‘tnet’ packages (Team, 2012). The weighted networks were visualized with the Social Network Image Animator (SoNIA) from Stanford University (Bender-deMoll & McFarland, 2003). The network visualizations were adjusted for clarity with Inkscape vector graphics.

Video fragments were first processed to improve the quality of the audio recordings. The fragments were subsequently watched and analyzed using the Transana video transcription software package (Woods & Fassnacht, 2012). The Transana software makes it possible to link textual transcriptions of conversations to video-fragments with an integrated option for labelling and coding. The last step of the video-ethnography was the organizing and structuring of labels. This was done with support of the Atlas.ti software package (Muhr, 2004).

4.6 Data analysis

We employ two methods to analyze the data: communication network analysis and video-observations. Network analysis revolves around relational data. Relational data is made up of nodes and ties. Independent of the domain in which it is applied, network analysis describes the field in terms of nodes – fixed entities, and ties – relations between the nodes. Nodes can be individuals, organizations, countries, or any other entity that can make up a setting for network analysis. Ties can be relations, alliances, communication channels or anything else that serves as a conduit for the flow of resources between nodes. Network analysis shows the patterns that rise from the interactions between nodes. In this study, nodes are made up by individual emergency response actors. These are the representing officers from the emergency services or other organizations involved. When multiple individuals from a single organization are involved, they are referred to as a single actor. Ties are formed by the interactions – when two or more actors speak to each other – that take place between emergency response actors.

Ties can be declarative and instrumental (Ibarra & Andrews, 1993). The ties that are created by the interactions between emergency response actors are instrumental. Declarative ties could have been used as well - for example by asking emergency response actors with which other actors they cooperated – but such an approach is less accurate for studying the exchange of information or coordination (Opsahl & Panzarasa, 2009). Ties can also be binary or weighted. Binary ties – there either is interaction or not – provide a strongly simplified view of what is going on within a team. Of course, network analysis is always insensitive to the contents of ties and the information that is exchanged, but reducing interaction to binary values removes much other information as well.

Most importantly, binary ties exclude the duration of the interaction and the moment at which the interaction takes place. To include the duration of interactions, this study makes use of valued or weighted ties. This means that ties between emergency response actors are weighted by the total duration of the interaction between the two actors. A last aspect of ties that is removed when binary ties are created is the moment at which a tie is established. Binary networks are two dimensional structures that do not reveal dynamics over time. To cover the moments at which interactions that place, it is necessary to track the timing of interactions. Since operational emergency response evolves over time, we explored the dynamics in the interaction networks.

Analyzing communication networks

Network analysis is primarily used in organizational research to study informal organizations (Krackhardt & Hanson, 1993). Network analysis has also been used to study the interactions that take place within teams (Balkundi & Harrison, 2006). Operational emergency management it both a team effort and a joint enterprise of multiple independent organizations that operate in a network structure. The independence of the emergency response actors, the absence of formal hierarchy, and the informal interactions between emergency response actors in the field make network analysis a logical method for analyzing the structure and operations of emergency response organizations.

The network approach to understanding organizations has found its way into research on emergency management before. The tension that has been observed between formal command and control structures and hectic emergency situations has caused researched to study the role of informal organizations during emergency response (Choi & Brower, 2006). Network analysis for emergency management is mainly aimed at inter-organizational networks that emerge in disaster response (Kapucu, 2005, 2006). Network analysis aimed at teams during emergency management is virtually non-existent, with exception of the work of Houghton *et al.* (2006) who studied the appropriateness of different network structures for emergency conditions. Network analysis is also increasingly used in research on serious gaming (Earnest, 2009; de Freitas & Liarokapis, 2011). The most frequently used application of network analysis for gaming is found in the analysis of massive multiplayer online (MMO) games (Claypool, LaPoint, and Winslow, 2003; Ducheneaut *et al.*, 2007; Suznjevic, Dobrijevic, and Matijasevic, 2009). Although network analysis is an upcoming research method in emergency management as well as serious gaming research, it has not yet focused on operational emergency management or virtual emergency exercises.

Connections, weighted connections, and time

Network analysis provides indicators of how information exchange and coordination take place within organizations. To do so for operational emergency response organizations, it is necessary to take the duration of interaction between emergency response actors into account. Analyzing weighted networks requires that some metrics need to be adjusted to process weighted ties (Opsahl & Panzarasa, 2009). To gain the best possible insight in the network structures, binary metrics and weighted metrics are produced simultaneously so that the values can be compared. Calculating centrality metrics for weighted networks is not as straightforward as it might seem. Where normal centrality metrics only take the number of ties into account, weighted centrality metrics must incorporate both the number and the weight of ties. Because the interpretation of weighted centrality metrics quickly becomes a complex affair, it is decided to operationalize weighted-degree centrality only and leave out other centrality metrics. The most challenging issue with calculating weighted centrality is in deciding upon the relative importance of the number of ties (the degree) in relation to the importance of the weight of ties (the strength). In other words, is it important to interact with many other emergency response actors or is it most important to interact with them for a longer time? Opsahl, Agneessens, and Skvoretz (2010) propose a tuning parameter to set the relative importance of degree versus strength. The parameter value can vary between 0 and 1, where a value of 0 means that no attention is paid to tie strength and the outcome becomes similar to degree centrality and a value of 1 means that the outcome is solely based on tie weights and the number of ties is disregarded. To gain insights in the relative importance number of interactions versus the duration of interactions, the weighted-degree centrality will be calculated with different values of the tuning parameters, ranging from 0 to 1 with intermediate steps of 0.1.

Operational emergency management evolves over time. This makes it useful to study the dynamics of interaction networks over time. Dynamic social network analysis is challenging, both conceptually as in the ways to manage data and visualize results. Balkundi & Kilduff (2006) argue that, given the importance of time sequencing to advance the understanding of the effects of network structures and the limited attention that is given to dynamics thus far, time effects form the core challenge for network analysis research. When moving from a fixed to a dynamic structure, a new arsenal of metrics and methods is required (Carley, 2003; Federico *et al.*, 2011; Federico *et al.*, 2012). Comprehensive ways to study the dynamics and evolution of network structures come with considerable costs of time and effort and the added value to explain organizational performance are doubtful (Federico *et al.*, 2011). For this research, we are interested in global trends like the increase or decrease of specific network characteristics. To reach this objective, a more basic assessment of network dynamics is proposed in the form of a fluctuation analysis of network metrics. The fluctuation analysis implies that changes of network metrics are calculated between relevant periods. The proposed analysis consists of a metrics to see whether the values of various network metrics increase, decrease or remain stable during the course of an emergency response. To measure such change, it is necessary to distinguish time periods between which an increase or decrease can be measured. This is done in the same way as the distinction that is made for emergency response processes, by distinguishing between an initial, intermediary, and final stage, of emergency response.

This study uses a variety of network metrics to analyze operational emergency response organizations. Network metrics are available for different levels of analysis, including the individual, group, and organizational level. Since this research is interested in performance at all three levels, network metrics are used for all three levels as well. This means that network characteristics are analyzed for individual emergency response actors, multidisciplinary subgroups, and on-scene command teams as a whole.

Actor positions

A range of network metrics is used to analyze the position of emergency response actors within communication networks. Common metrics to determine the centrality of nodes in a network are degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality (Okamoto, Chen, and Li, 2008). Degree centrality is the most straightforward of centrality metrics and is derived from counting the number of ties between a node and other nodes. Nodes that have ties to many other nodes have a high degree centrality and can be characterized as being well connected (Scott, 2011). Emergency response actors have a high degree centrality when they speak with many other actors in the course of the response. Betweenness centrality is a more complicated measure. Betweenness centrality indicates the extent to which a node lies between other nodes within a network. The relevance of betweenness centrality is that it indicates the extent to which a node acts as a 'mediator', and thereby provides an intuitively meaningful indicator of a node's importance within a network (Scott, 2011). An explanation of the calculating process for betweenness centrality is provided by Scott (2011, p. 87). Emergency response actors with a high betweenness centrality occupy important positions between other actors in the response. A third centrality measure is closeness centrality. Closeness centrality indicates the graph-theoretic distance of a node to all other nodes within a network (Newman, 2008). The value of calculating closeness centrality is that it provides an indicator of a nodes ability to reach other nodes and whether a node can quickly be reached by other nodes or not. Low closeness centrality of an emergency response actor in a communication network can indicate that the actor is difficult to contact for other actors. The last centrality measure that is presented here is eigenvector centrality. The strength of eigenvector centrality is that it takes the importance of other nodes into account. Where degree centrality only measures to the number of nodes to which a node is connected, eigenvector takes the centrality of the other nodes into account as well. In terms of importance in an emergency response communication network: it is not so much relevant with how many other actors speak, but whether you speak to important actors. The calculation of eigenvector centrality is also relatively complex, an explanation is provided by (Bonacich, 2007). Weighted-degree centrality is included and calculated as explained in above to include the duration of communication between emergency response actors. The definitions of the network metrics employed in this study and their meaning in the context of emergency response communication networks is listed in table 4.2.

Subgroups in networks

Measuring the presence and position of subgroups within emergency response communication networks is more challenging than measuring the position of individual actors. The first challenge is to measure whether subgroups are present within a network. This can be done by calculating the clustering coefficient of a network. The clustering coefficient provides an indicator of the tendency of nodes to cluster together by calculating the density of triplets in a network (Ravasz & Barabási, 2003). The concept of a triplet forms the core of the clustering coefficient. Network analysis distinguishes open and closed triplets. Open triplets consists of three nodes that are connected by two ties while closed triplets are made up by three nodes that are connected by three ties, i.e. that are fully connected. The global clustering coefficient is defined as the number of closed triplets over the total number of triplets (Opsahl & Panzarasa, 2009).

Network measure	Definition	Operationalization
Degree centrality	The number of connections between a node and other nodes.	The number of other emergency response actors that an actor in question is communicating with.
Betweenness centrality	The faction of shortest paths between node pairs that pass through the node of interest.	The number of times that an actor in question is at the shortest communication path between two other emergency response actors.
Closeness centrality	The total graph-theoretic distance of a given node from all other nodes.	The distance (number of communication steps) of an actor in question to all other emergency response actors.
Eigenvector centrality	The weighted sum of the direct and indirect connections between a node and other nodes.	The importance of an emergency response actor in question derived from its communication with other important emergency response actors.
Weighted-degree centrality	The value of the connections between a node and other nodes.	The number of emergency response actors and the duration of the communications of an actor in questions as a proportion of the maximum number of actors in the response and the maximum duration of communication.

Table 4.2 - Centrality metrics to study the position of nodes in networks

The clustering coefficient of any network has a value between 1 and 0. A value of 1 is obtained with a closed network (all triplets are closed) and 0 when not a single closed triplet can be found. For emergency response networks, the clustering coefficient indicates the tendency of the emergency response actors to form subgroups of at least three actors. This provides a relevant insight for the analysis of coordination of multidisciplinary tasks that require more than two actors. The presence of subgroups – measured with the clustering coefficient – is more likely, and beneficial when an emergency involves multidisciplinary tasks.

To analyze the presence of subgroups within a communication network, it makes sense to include the duration of communication as well. A subgroup that communicates longer is likely to exchange more information or coordinate more than a subgroups that communicates briefly. The clustering coefficient does not take the duration of communication between actors into account and including tie weights is a challenge. A method to incorporate weight has been proposed by Opsahl & Panzarasa (2009) who developed the generalized clustering coefficient.

The generalized clustering coefficient measures whether stronger ties are more likely to be part of closed triplets than weaker ties. In other words, a high weighted clustering coefficient indicates that a network involves many closed triplets and that these triplets are likely to be formed by nodes that are strongly connected. Calculating the generalized clustering coefficient is done with a triplet value. By incorporating the value of triplets, it is possible to determine whether the strength of ties that make up a triplet influence the likelihood that the triplet is closed and hence forms a cluster. One of the difficulties of the generalized clustering coefficient lies in the determining of triplet values. Opsahl & Panzarasa (2009) present four ways to calculate triplet values: the arithmetic mean, the geometric mean, and the maximum or minimum value of the weights of the ties that make up the triplet. What method is appropriate depends upon the context and research question. We take the average amount of communication that is taking place within a subgroup. There is no reason to assume that extreme values of a single tie will distort the outcome – and therefore must be compensated by calculating the geometric mean – so the arithmetic mean will be used. The weighted clustering coefficient calculated with triplet values based on the arithmetic mean will serve as an indicator of the tendency of emergency response actors to form subgroups in which much communication takes place.

Network measure	**Definition**	**Operationalization**
Clustering coefficient	The number of closed triplets (three completely connected nodes) as a proportion of the total number of triplets (three completely and incompletely connected nodes).	The tendency of emergency response actors to form subgroups of three or more actors in which all actors communicate with each other.
Generalized clustering coefficient	The value of closed triplets as a proportion of the total value of all triplets.	The tendency of emergency response actors to form subgroup of three or more actors and to communicate more with these actors than with others.

Table 4.3 - Clustering coefficients to study the presence of subgroups in networks

Structural network characteristics

The communication of all emergency response actors combined forms a network structure that can be analyzed. Network density forms the primary indicator of network level structures. Density is also a key measure in network analysis for organizations and teams thus far. Density is defined as the "number of lines in a graph, expressed as the proportion of the maximum number of lines" (Scott, 2011, p. 71). Applied to operational emergency management, density is the number of emergency response actors that communicate with each other as a proportion of the maximum number of possible actors that communicate with each other.

The duration of communication can be included in the calculation of communication network density. Instead of looking at the number of ties as a proportion of all possible ties only, weighted density is based on the number of ties and their weights as a proportion of all possible ties and their maximum weights. Calculating weighted density requires that the maximum weight of network ties is known. This is the case for communication in operational emergency response where the maximum duration of communication is determined by the length of the emergency response. Because weighted density includes the duration of the communication between emergency response actors, it provides a more accurate indicator of the amount of communication in an emergency response communication networks than the general density measure.

Network measure	Definition	Operationalization
Density	The number of connections in a network as a proportion of the maximum number of connections in a network.	The number of emergency response actors that communicate with each other as a proportion of the total number of emergency response actors that can communicate with each other.
Weighted density	The number of nodes that are connected and the weights of the connections as a proportion of the maximum number and weight of connections in the network .	The number of emergency response actors that communicate with each other and the duration of the communication as a proportion of the total number of emergency response actors that can communicate with each other and the maximum duration of the communication.

Table 4.4 - Density metrics to study characteristics of communication networks

4.7 Conclusion

This chapter revolved around the question how the important factors in the process of emergency response and emergency management performance can be operationalized for empirical observation and comparative analysis. The research is based on a pragmatic research strategy that combines and mixes different research methods to systematically develop a rigorous account of how operational emergency management performance comes about. The combination of research methods helps to structure the analysis and to develop warranted assertions regarding the complex processes that determine emergency management performance.

The important factors in the process of emergency response from the analytical research framework and emergency management performance are operationalized for observation and analysis with different research methods. Situational awareness, emergent coordination and collective sensemaking are analyzed by relating structural qualities of emergency response communication networks to emergency management performance. We introduce several hypothesis that describe the expected relation between communication network characteristics and performance to guide the empirical observations and analysis. The important factors, including emergency decision-making, are further analyzed through the observation and comparison of purposively selected video clips of (inter)actions between emergency responders in the exercises and from the post-exercise evaluations. Emergency management performance is assessed with a performance composite that combines emergency response process characteristics and outcomes to obtain performance scores.

Data is collected during twenty virtual reality exercises that are systematically observed, analyzed and compared to develop an empirical account of operational emergency management performance. The data is collected through video-observations, questionnaires and interviews. The data is subsequently processed to enable communication network analysis and video-observations. The data is analyzed by applying communication network metrics that provide insights in the structural characteristics of communication in emergency response organizations. The (inter)actions that result in variation in emergency management performance are traced through the systematic and comparative analysis of video observations.

Chapter 5
Emergency management performance

5.1 Introduction

Emergency management performance forms the dependent variable in our analytical framework and variation of emergency management performance is the core issue that we try to explain in this research. Describing and analyzing variation in the performance of emergency responders is therefore a key step in our analysis. This chapter presents the results of the virtual reality exercises studied by asking: what variation is observed in emergency management performance?

Emergency management performance is analyzed at several levels. First, variation observed with regard to performance of individual response tasks and response actors is presented. Second, we describe and analyze variation in the performance of multidisciplinary subgroups. And third, we present variation in the performance of on-scene command teams as a whole. The main workings questions are which actors, groups or teams perform better than others? And what relations do we find between the performance on individual emergency response tasks, the performance of emergency response actors, and the performance of on-scene command teams as a whole?

The chapter starts by describing the overall variation of performance scores and discussing surprising outcomes in section 5.2. We continue with three sections that provide a more elaborate presentation and analysis of performance at the level of emergency response tasks (section 5.3), emergency response actors and multidisciplinary subgroups (section 5.4), and on-scene command teams as a whole (section 5.5). Section 5.6 discusses the outcomes of the performance assessment against the comments from post exercise evaluations to check the face validity of our findings. Section 5.7 discusses relations and dependencies between performance at different levels. The concluding section (section 5.8) returns to the central question of this chapter by providing an overview of the main outcomes of the performance assessment.

5.2 Handling multiple response tasks

The assessment of operational performance was structured and performed as explained in chapter four. By providing scores to emergency response tasks, either when they were taken care of or when outcomes were achieved, a multilevel assessment of team performance is established. The outcomes of the performance assessment reveal how actors and teams have paid different amounts of attention to different emergency management objectives.

Our analysis of the outcomes of the operational emergency management performance assessment starts at the level of emergency response tasks. The outcomes of the performance assessment are shown in the exercise radar charts presented in figures 5.1-5.4. The axes of the charts present the emergency response tasks that were part of the specific scenarios. The performance scores obtained by all on-scene command teams that took part in each exercise scenario are plotted on the axes.

Abundant variation and unexpected performance scores

The charts in figures 5.1-5.4 reveal two aspects of the observed performance. First, there is abundant variation between task performance scores. Second, some performance scores are unexpectedly high given the characteristics of the exercise scenarios. Both aspects are discussed.

A look at the radar-charts reveals that there was ample variation in operational emergency management performance in all scenarios. There was no emergency response task in the four scenarios for which a similar performance score was obtained by all teams. The charts provide many examples of differences in task performance, to highlight a few:

1. In the Westerschelde Tunnel hazardous materials scenario, teams five and six obtained higher performance scores for recovery operations than teams one, three and four. In the same scenario, teams three and four obtained high performance scores – as compared to the other teams – for the evacuation and shelter of victims.
2. In the Westerschelde Tunnel evacuation scenario, teams two and four performed better with regard to traffic management than teams one and three.
3. In the Port carbon monoxide scenario, team one obtained a low performance score for the measuring of hazardous materials while the same team performed well in escorting emergency response units towards and from the emergency location.

The discovery of variation on all emergency response tasks is an interesting finding in itself. We started off in search for (at least some) variation in the performance of actors and on-scene command teams on key response tasks in the exercise scenarios. The observed variation is significant and shows that performance varies for all emergency response tasks. The fact that performance scores vary with regard to all response tasks indicates that differences in how emergency response comes about exist with regard to all tasks that are part of emergency response. Although the most substantial part of the observed variation is the result of true differences in how tasks were managed, another part seems due to other factors. These 'additional' factors are briefly discussed.

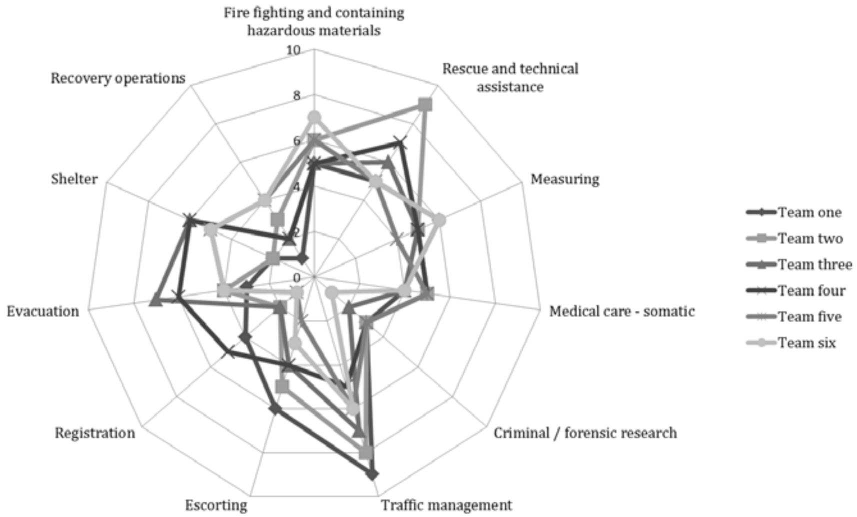


Figure 5.1 – Task performance in the Westerschelde Tunnel hazardous materials scenario

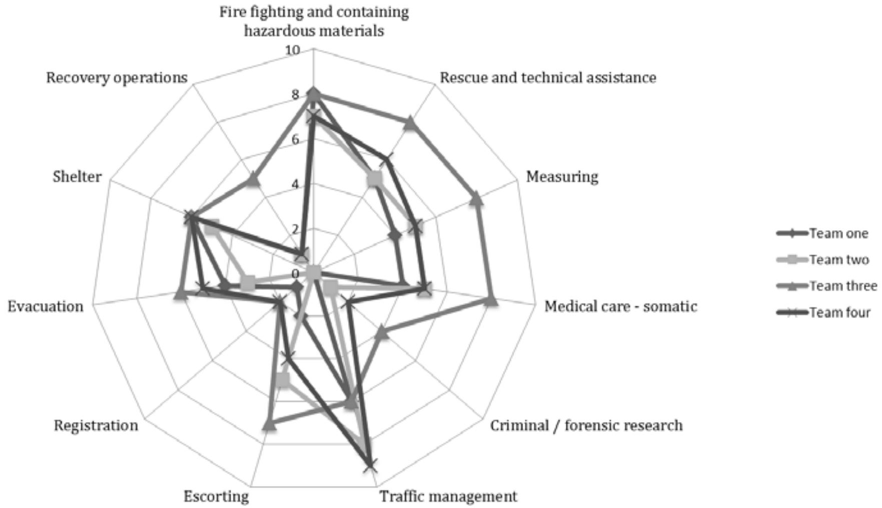


Figure 5.2 - Task performance in the Westerschelde Tunnel evacuation scenario

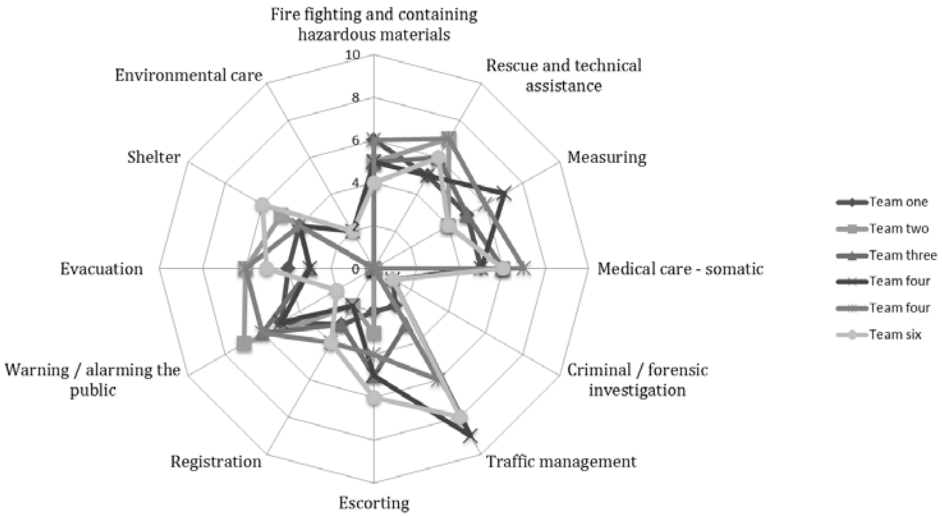


Figure 5.3 – Task performance in the urban hazardous materials scenario

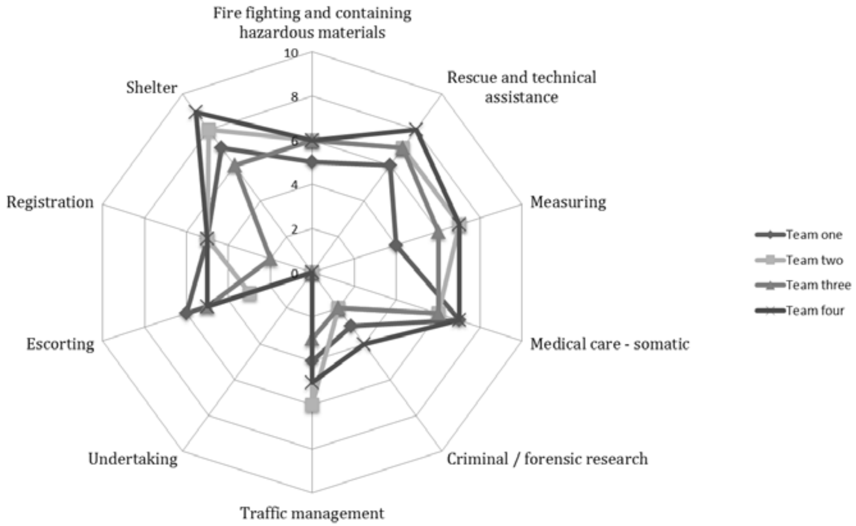


Figure 5.4 - Task performance in the port carbon monoxide scenario

The radar charts include several unexpected performance scores, such as the scores that exceed the expected maximum score on basis of the characteristics of the exercise scenarios. Chapter three explains how emergency response tasks have expected maximum scores, based on their position in the larger emergency response effort. These scores are sometimes exceeded, for example in the Urban hazardous materials scenario, where traffic management is expected to receive a maximum score of 6 because the task is not expected to be initiated before the intermediate phase of the emergency response. The chart in figure 5.3 shows that the performance scores for traffic management in the Urban hazardous materials scenario run up to 8 and 9 points for two teams. The maximum expected performance score is also exceeded for several other emergency response tasks in other scenarios. Closer inspection of these high performance scores made clear that overruns of the expected maximum performance have two causes.

In some cases, the tasks were assigned to certain phases of the emergency response but, due to the fast execution of tasks in previous phases, could be started up sooner than expected. In the Port carbon monoxide scenario, for example, the rescue of victims can start so quickly that shelter and medical care can be started as well during the initial stage of the emergency response. The exercise scenario developers made conservative judgments on the speed by which these tasks could be managed. Since these actions were legitimate, the performance scores were kept in the assessment and used for the remainder of the research.

The second reason for unexpected performance scores is that the exercise staff erroneously released information that allowed participants to initiate tasks earlier than intended on two occasions. In the fourth exercise involving the Urban hazardous materials scenario, the advisor on hazardous materials joint in the exercise immediately. The exercise staff should have prevented this because the advisor normally arrives later than the first responders. However, the exercise staff did not intervene but instead released information to the fire services about carbon monoxide levels. This mistake resulted in a change of tasks for the fire services and the advisor on hazardous materials, making it possible for them to obtain higher performance scores than other teams. The erroneous release of information had a more elaborate effect in the third team that took part in the Westerschelde Tunnel evacuation scenario. In this team, the exercise staff accidentally released information on the toxicity levels of the smoke and number of victims, making it possible for the participants to start the tasks of rescue and medical care earlier than intended. This resulted in much higher overall performance than other teams in the same scenario. Because these high performance scores were the result of mistakes by the exercise staff, the scores were adjusted to the average performance score for the remainder of the research. Keeping these scores would wrongfully influence the relation between emergency management processes organized by the emergency response actors and performance. The adjustments did not have a significant effect on the overall outcomes.

5.3 Emergency response task performance

The analysis of emergency response task scores forms the lowest and most elementary level of our assessment of operational emergency management performance. Before continuing to performance at the aggregated levels of emergency response actors, multidisciplinary subgroups, and on-scene command teams, the variation in task performance is analyzed. Since it is difficult to obtain a clear overview of the scores on basis of visual comparison of the radar-charts in figures 5.1 to 5.4, several indicators are used to describe variation. These indicators are used to identify deviant performance scores and describe patterns in the range and distribution of performance scores. The indicators to describe performance scores are:

1. Deviance: scores that are at least two points higher or lower than the average performance score in an exercise scenario;
2. Variation:
    a. The range (R): the difference between the highest and the lowest score in an exercise scenario;
    b. The dispersion or standard deviation (SD): the amount of variation in the performance scores in an exercise scenario.

Deviant task performance scores

Performance scores are labelled as deviant when they differ more than 2 points from the average performance score of a task in a specific scenario. By using a two point difference, the ‘normal’ variation that is observed in performance for all emergency response tasks is left aside and only scores that are distinctively better or worse than most others are identified. Identifying deviant performance scores with this method helps to select the best and worst performance scores of tasks, actors, and multidisciplinary subgroups. This section presents deviant performance scores of emergency response tasks.

Two performance scores stand out in the Westerschelde Tunnel hazardous materials scenario. First, the rescue and technical assistance task is performed particularly well by team two. As can be seen in figure 5.1, team two does not outperform the other teams in other emergency response tasks but excelled only in the rescue task. There were no specific remarks about the rescue tasks in the post-exercise evaluation that explain this peak performance and it is interesting to see if the analysis of emergency management processes in the next chapter can shed light on what caused the team to perform so well with regard to this particular task. Second, the tasks concerning population care – evacuation, shelter, and registration – receive varying performance scores. Evacuation and shelter were successfully taken care of by teams three and four although only team four was outperforming the others with regard to registration. Team five, in contrast, was successful at registration but shows poor performance regarding evacuation and shelter. These deviations indicate that tasks were handled differently by different teams. The discrepancies between performance scores for evacuation and shelter on the one hand and registration on the other are not surprising as these tasks were executed in relative independence of each other. The variation in performance scores with regard to the population care tasks in the Westerschelde Tunnel hazardous materials scenario form interesting input for further analysis of how emergency management processes result in performance. This aspect returns in the discussion of multidisciplinary subgroup performance scores in section 5.4.

In the Westerschelde Tunnel evacuation scenario, a series of peak scores is obtained by team three. While other teams receive comparable performance scores, team three outperforms the other teams in seven of the total of eleven emergency response tasks. Deviant performance scores are obtained for measuring, medical care, and recovery operations. Section 5.2 describes how the extreme performance of team three in the Westerschelde Tunnel evacuation scenario was caused by the erroneous release of information by the exercise staff. The performance scores were therefore adjusted for the remainder of the analysis. No other deviant performance scores were obtained by the teams that participated in the Westerschelde Tunnel evacuation scenario.

The performance scores of the Urban hazardous materials scenario include two peak performance scores. One peak concerns the traffic management task that was performed significantly better by teams four and six. Inspection of the post-exercise evaluations made clear that the police in teams four and six decided early on to call for an additional police officer to manage traffic in the surroundings of the emergency location. The other teams waited longer to call for assistance or did not call for assistance at all. The early assistance of an additional officer explains the high performance scores for traffic management. The other peaks are observed with regard to the task of warning and alarming the public. This task is unique for the Urban hazardous materials scenario. The performance score obtained by team six is exceptionally poor. Since warning and alarming the public is a multidisciplinary task, the causes of this low performance are further explored in section 5.4 that deals with multidisciplinary subgroup performance.

The performance assessment of the Port carbon monoxide scenario contains two exceptional performance scores. Team one receives a significantly poor performance score for measuring while team three performs poorly on registration. The post-exercise evaluations did not bring up special reasons for why these particular performance where poor and the deviant scores remain open for further explanation in the analysis of emergency management processes. The Port carbon monoxide scenario also included the undertaking task for which none of the teams obtains a performance score. This is due to the fact that the task did not receive any significant attention during the exercises. The undertaking task is therefore excluded from further analyses. Deviant task performance scores in the four emergency scenarios are listed in table 5.1.

***Westerschelde Tunnel* hazardous materials scenario**
Deviant (positive) performance by team two on rescue and technical assistance
Significant variation (positive and negative deviant performance scores) for population care tasks (evacuation, registration, and shelter)
***Westerschelde Tunnel* evacuation scenario**
Deviant (positive) performance scores for team 3 (result of erroneously release of information by exercise staff)
Urban hazardous materials scenario
Deviant (positive) performance on traffic management by teams four and six
Deviant (negative) performance of team six for warning and alarming the public
Port carbon monoxide scenario
Deviant (negative) performance of team one on measuring
Deviant (negative) performance of team three on registration

Table 5.1 – Deviant emergency response task performance scores

Variation in task performance

The performance scores for some emergency response tasks varied stronger than the performance scores obtained for others. For example, performance scores for medical care are more or less equal for different teams with scores of 5 and 6 while performance scores for registration swing between 1 and 5 in the Westerschelde Tunnel hazardous materials scenario. It is interesting to track this kind of variation as it can indicate something about the nature of the emergency response task or about the way in which the task was managed. When task performance is relatively similar, the task either leaves little room for variation or all participants manage the task in a similar way. When task performance varies, the task might be more ambiguous by nature or the participants might have different ways to take care of the task. The variation of task performance is analyzed by looking at the range (R) – the difference between the highest and lowest score – and standard deviation (SD) of the performance scores. The range shows the total variation between tasks scores while the standard deviation forms an indicator of the spread of the scores. The higher the standard deviation, the more the scores lie apart. The outcomes of the analysis are summarized.

The range of task performance scores varies between 1 and 9. The range of 9 stems from the traffic management task in the Urban hazardous materials scenario. The reason for this variation is discussed with the unexpected results in section 5.2. If this exceptional score is neglected, the highest ranges are observed for escorting in the Westerschelde Tunnel evacuation scenario and warning and alarming the public in the Urban hazardous materials scenario. The range of performance scores for these tasks is both 5. The average range of the task scores varies as well with a minimum of 1.5 for firefighting and containing hazardous materials and a maximum of 4 for escorting[7]. The same counts for the average

[7] The average range of traffic management (4.8) is discarded as it is strongly influenced by the exceptional range of 9 in the Urban hazardous materials scenario. The average range of warning and alarming the public (5.0) is excluded as the task is only part of the Urban hazardous materials scenario.

standard deviations that were low for firefighting and high for escorting. Since this study has special interest in the recovery of infrastructure disruptions, we highlight that the range and standard deviation of the performance scores obtained for recovery operations are relatively high, indicating that infrastructure recovery is performed with varying success.

The analysis of variation in performance scores shows that the core tasks of traditional emergency services – firefighting, rescue, medical care, criminal and forensic research - are performed with less variety than more peripheral tasks like measuring, escorting, and shelter. Also, less variety is observed in the performance scores of monodisciplinary emergency response tasks than in the performance scores of multidisciplinary tasks.

Performance of monodisciplinary versus multidisciplinary tasks

Exploring the average range and standard deviation of performance scores (excluding the exceptional variation in performance found for traffic management in the Urban hazardous materials scenario), a difference is observed between mono- and multidisciplinary task performance scores. Monodisciplinary task performance scores show an average range of 2.3 while the average range of multidisciplinary task scores is 3.2. The same trend is observed for the standard deviations that are 1.0 on average for monodisciplinary tasks and 1.4 for multidisciplinary tasks. In sum, performance scores obtained for tasks that are handled by multiple emergency response actors vary more.

This finding can have different causes. First, it may be the case that multidisciplinary tasks are more complex than monodisciplinary tasks, leaving more room for different responses and thereby different performance scores. However, this would mainly result in different scores on the extent to which objectives were achieved and not on the amount of attention paid to a task. Whether actors take care of a task or not is unrelated to the complexity of the task. Closer inspection of the performance scores makes clear that the differences observed are not due to variation in the 'achievement' component of the performance scores alone. The increased variation of multidisciplinary performance scores can therefore not be attributed to the complexity of the task.

Second, the differences in variation of performance scores can be due to the fact that actors are more capable of taking care of monodisciplinary tasks than multidisciplinary tasks. The additional variation in multidisciplinary task performance is then due to a lack of skill in performing multidisciplinary tasks. However, we noticed that all actors have the same level of knowledge and skills to perform tasks (see section 3.4) and the post-exercise evaluations did not provide any indications to alter this assumption.

A third explanation is that the additional variation in multidisciplinary task performance is due to difficulties of coordination. By definition, monodisciplinary tasks do not require coordination between actors. The additional variation in the performance of multidisciplinary tasks might therefore be due to difficulties in coordination. This explanation is supported by further analysis of the task performance scores that includes the number of actors involved in a task. Tasks that involved two actors – traffic management, escorting, recovery operations, and environmental care – have an average performance score range of 2.9 and an average standard deviation of 1.3. Tasks that involved more than two actors – registration, evacuation, and warning and alarming the public – have an average performance score range of 3.7 and an average standard deviation of 1.5. Similar to the overall averages, these averages have been calculated without the exceptional variation observed for traffic management in the Urban hazardous materials scenario. The tasks that involve more than two actors are not more complex or less common than the tasks that are handled bilaterally. The increased variation in performance that is found when more actors are involved in an emergency response task suggests that coordination plays an important role in explaining variation in emergency management performance.

5.4 Actor and multidisciplinary subgroup performance

Emergency response actors take care of multiple emergency response tasks. The performance of emergency response actors is therefore assessed by adding up the performance scores of the tasks in which actors are involved. Multidisciplinary subgroups consist of multiple emergency response actors that are jointly responsible for one task. The performance of multidisciplinary subgroups is therefore assessed on basis of the performance score of the task involved. The performance of emergency response actors is presented and discussed first, followed by the performance of multidisciplinary subgroups.

The performance of emergency response actors is analyzed in terms of strong and weak performance scores and the variation of performance scores between different actors. The performance scores of all actors in each scenario were listed in tables to enable a first, visual comparison. After that, the range and standard deviation of the performance scores of the actors in the same scenario were calculated. The performance scores of actors were normalized and ranked from highest to lowest performing actors to provide a systematic overview. The normalization and ranking of performance scores showed how the performance scores of actors operating in the same scenario were distributed. Table 5.2 shows the normalized performance scores of the fire services as an example. The performance scores of the fire services in the Westerschelde Tunnel hazardous materials scenario are almost equally distributed between the highest and lowest performing participants, with a maximum interval of 0.29. The performance scores of the fire services in the Westerschelde Tunnel evacuation scenario are characterized by one high performing participant (creating an interval of 0.87 between the highest and second highest score) while the performance scores of fire services in the Urban hazardous materials and Port carbon monoxide scenarios are characterized by one low performing participants (with intervals of 0.43 and 0.67). A similar assessment was performed for the other emergency response actors. There is no value in discussing the performance of *all* actors in the four exercise scenarios. However, deviant performance scores – deviant in the sense that a gap of more than two times the standard interval between normalized performance scores existed between the highest or lowest performing actor(s) and the second highest or lowest performing actor(s)[8] in a given exercise scenario – are discussed, followed by a discussion of the variation in actor performance scores.

Team / scenario	Westerschelde Tunnel hazardous materials scenario	Westerschelde Tunnel evacuation scenario	Urban hazardous materials scenario	Port carbon monoxide scenario
Highest performing	Fire services 2 (1.00)	Fire services 3 (1.00)	Fire services 5 (1.00)	Fire services 4 (1.00)
↓	Fire services 6 (0.71)	Fire services 1 (0.13)	Fire services 4 (0.86)	Fire services 2 (0.83)
	Fire services 5 (0.57)	Fire services 4 (0.13)	Fire services 2 (0.71)	Fire services 3 (0.67)
	Fire services 4 (0.43)	Fire services 2 (0.00)	Fire services 3 (0.57)	Fire services 1 (0.00)
	Fire services 3 (0.29)		Fire services 1 (0.43)	
Lowest performing	Fire services 1 (0.00)		Fire services 6 (0.00)	

Table 5.2 - Normalized performance scores of the fire services

Deviant performance scores of emergency response actors

Several actors stand out in the Westerschelde Tunnel hazardous materials scenario as they obtained significantly better or worse performance scores than their peers. The police officer of team one significantly outperforms his peers as did the medical emergency services officer and the municipal offer of team four. Deviant negative performance scores are obtained by the tunnel guard in team four and the police officer of team six. The post-exercise evaluations did not indicate specific conditions that explain these aberrations. The deviant performance scores are therefore kept for further analysis.

We explained in section 5.2 why team three in the Westerschelde Tunnel evacuation scenario performs well as a result of a mistake by the exercise staff. It does not come as a surprise therefore that actors that are part of team three performed better than

[8] The choice of what constitutes a deviant score is subjective, similar to determining what constitutes an outlier in statistical analysis. The decision to identify actor scores as deviant when they differ more than two times the standard interval between performance scores is used because it proves to be a useful method to identify actors that perform substantially better or worse than others. The standard interval between normalized scores in scenarios in which six teams took part is 1.0/6=0.17. An actor's performance score is therefore deviant in these exercises when a gap of 0.34 or more exists between the highest or lowest, and second highest or lowest performing actor(s). The standard interval between scores in scenarios in which four teams took part is 1.0/4=0.25 which means that a gap of 0.50 or more must be encountered before a score is labelled as deviant.

their peers. It is worth mentioning that the tunnel operator and the municipal officer of team three do not significantly outperform their peers. These actors were not able to benefit from the premature release of information by the exercise staff. The actors of other teams in the Westerschelde Tunnel evacuation scenario obtained relatively similar performance scores and no deviant scores are identified.

The performance scores of actors in the Urban hazardous materials scenario are relatively stable. Strong variation is observed for the police officers that were, among others, responsible for traffic management. The variations in performance scores for traffic management have been explained in section 5.2 and the variations are considered to be an natural factor in the performance of the police. As a result, the police in teams four and six obtain significantly better performance scores than their peers while the police in team one performs significantly worse. Besides the differences in performance of the police, three performance scores stand out. The fire services officer of team six and the medical emergency services and police officers of team one deliver a poor performance. There were no specific comments in the post-exercise evaluations that explain these aberrations which means that the deviant performance scores are kept for further analysis.

The performance scores of the actors of team three stand out negatively in the Port carbon monoxide scenario. All actors in this team perform less than their peers but not all performance scores are sufficiently poor to pass the threshold of a deviant score. The performance of the police officer and the municipal officer are significantly poorer than their peers. The fire services and advisor on hazardous materials form an exception as their performance scores are closer to the scores of their peers. Deviant performance scores are observed in other teams as well. The advisor on hazardous materials of team one obtained a significantly lower performance score than his colleagues in the other teams. So do the fire services of team one. The fact that the performance scores of the fire services and advisor on hazardous materials seem related is interesting but not surprising. Their task are closely related and the fire services cannot operate well without assistance from the advisor on hazardous materials. The deviant performance scores of actors in the different scenarios are listed in table 5.3.

Westerschelde Tunnel hazardous materials scenario
Actors with significantly better performance scores than their peers: Police in team one, medical emergency services team four, municipality team four
Actors with significantly lower performance scores than their peers: Tunnel operator in team four, police in team six
Westerschelde Tunnel evacuation scenario
Actors with significantly better performance scores than their peers: -
Actor with significantly lower performance scores than their peers: -
Urban hazardous materials scenario
Actors with significantly better performance scores than their peers: Police in teams four and six
Actor with significantly lower performance scores than their peers: Police in team one, fire services in team six, medical emergency services in team one
Port carbon monoxide scenario
Actors with significantly better performance scores than their peers: -
Actor with significantly lower performance scores than their peers: Police in team three, municipality in team three, fire services in team one, advisor on hazardous materials in team one

Table 5.3 - Deviant emergency response actor performance scores

More negative than positive deviant performance scores are observed for emergency response actors. Positive aberrations are observed in the Westerschelde Tunnel hazardous materials scenario and the Urban hazardous materials scenario. The positive scores in the Westerschelde Tunnel hazardous materials scenario are all related to actors involved in *population care* and are discussed in the next section on multidisciplinary subgroups. The positive performance scores in the Urban hazardous materials scenario are related to decisions of the police to call for assistance. Deviant negative performance scores are observed in all exercise scenarios except for the Westerschelde Tunnel evacuation scenario. The negatively deviant performance scores of emergency response actors are spread over different teams without any apparent pattern. It seems that emergency response actors are less likely to excel and perform better than average and more likely to fail and perform significantly poorer than their peers.

Variation in actor performance

The variation between the performance scores obtained by the emergency response actors is analyzed by calculating the range (*R*) and the standard deviation (*SD*) of the performance scores. The outcomes are shown in table 5.4.

The amount of variation between performance scores of actors indicates that tasks were sufficiently complex to be achieved in different ways and that the actors involved managed the tasks differently. The performance scores of the fire services, tunnel operator, and advisor on hazardous materials are stable over the different scenarios compared to the other actors. The performance score ranges of the fire services differ 2 points between the different exercise scenarios, the tunnel operator scores differ 0 points, and the scores of the

	Fire services		Medical services		Police		Munici-pality		Team leader		Tunnel operator		Adv. on haz. mats	
	R	*SD*	*R*	*SD*	*R*	*SD*	*R*	*SD*	*R*	*SD*	*R*	*SD*	*R*	*SD*
Westerschelde Tunnel hazardous materials scenario	7	2.4	8	3.1	10	4.0	9	3.6	8	3.2	4	1.4	3	1.2
Westerschelde Tunnel evacuation scenario	8	3.7	12	5.3	12	5.3	6	2.6	27	12	4	1.7	4	2.0
Urban hazardous materials scenario	7	2.5	7	3.0	9	4.2	4	2.0	14	5.7			4	1.6
Port carbon monoxide scenario	6	2.6	5	2.4	7	3.2	6	2.6	13	5.7			4	1.9
Average	7.0	2.8	8.0	3.4	9.5	4.2	6.3	2.7	16	6.6	4.0	1.6	3.8	1.7

Table 5.4 - Variation of actor performance scores in the four scenarios

advisor on hazardous materials 1 points as compared to a difference of 7 for the medical services, 5 for the police, 5 for the municipality, and 19 for team leaders.The variation of performance scores, indicated by the standard deviation, is comparatively high in the Westerschelde Tunnel evacuation scenario as compared to the other scenarios. This is explained by the exceptional performance of the third team – including a strong performance of the fire services – that took part in this scenario and that is discussed in section 5.2. This effect is most profound for the medical emergency services and the police.

The performance scores of these actors show a more variation between the different scenarios than the performance of the fire services. Most variation is observed for the Westerschelde Tunnel evacuation scenario. Both the range and the standard deviation for the performance scores of both the medical emergency services and the police in this scenario are high. These peaks are also explained by the extremely high performance score of the third team. The performance scores of team three in the Westerschelde Tunnel evacuation scenario are adjusted for further analysis because the performance score of team three is partially dependent on a mistake by the exercise staff. When the peak performance scores obtained by the third team in the Westerschelde Tunnel evacuation scenario are left aside, the differences between the variation in the performance scores of the fire services and other emergency response actors remain. The performance scores of the fire services have a lower range and standard deviation than the performance scores of other emergency response actors. The performance scores of the medical emergency services and the police vary most.

The performance scores of the traditional emergency services show more variation than the performance scores of the tunnel operator and the advisor on hazardous materials. This difference is largely explained by the fact that the traditional emergency services are responsible for more emergency response tasks. With fewer tasks at hand, the range and standard deviation of performance scores of more peripheral actors were naturally lower. The difference in variation disappears when the variation in actor performance scores is controlled for the number of tasks in which an actor was involved. In fact, the variation of actors involved in less tasks was slightly higher, which is explained by the fact that different task scores compensate each other, making variation in task performance less visible when an actor performs more tasks. The variation of performance scores of the team leader are based on the aggregated performance scores of all emergency response tasks. The performance of team leaders is therefore similar to the performance of the on-scene command team as a whole (discussed in section 5.5).

Variation in the performance of multidisciplinary subgroups

Emergency response tasks were, besides emergency response actors, management by multidisciplinary subgroups. As explained in chapter two, multidisciplinary subgroups are formed in emergency response organizations to deal with multidisciplinary tasks that require cooperation and coordination between multiple actors. Because subgroups are formed with regard to specific emergency response tasks, an assessment of subgroup performance is similar to the assessment of multidisciplinary response tasks. The assessment of response task performance in section 5.3 showed that multidisciplinary tasks are performed with more variation than monodisciplinary tasks. This section describes the variation and highest and lowest performance scores of multidisciplinary subgroups in the four exercise scenarios.

An important multidisciplinary subgroup in the scenarios involving the Westerschelde Tunnel hazardous materials scenario was formed by the fire services and the tunnel operator who were together responsible for recovery operations. The variation of the recovery operations task is significant, indicating that the task is handled differently by different teams. However, none of the teams involved in a Westerschelde Tunnel exercise scenario obtained a deviant performance score. Variation of performance scores is slightly bigger in the Westerschelde Tunnel evacuation scenario (range (R) = 4, standard deviation (SD) = 2.0) than in the Westerschelde Tunnel hazardous materials scenario (range (R) = 3, standard deviation (SD) = 1.2). There are no intrinsic differences between the scenarios or comments from the post-exercise evaluations that explain this difference. The difference is therefore an interesting outcome for further inquiry.

An important multidisciplinary subgroup that played a role in all four emergency scenarios is the group of actors involved in 'population care'. This group generally consists of the medical emergency services, the police, and the municipality. These actors are together responsible for the evacuation and registration of injured and non-injured victims involved in an emergency. Shelter is also part of population care but is a monodisciplinary taken care of by the municipality. There are no significant aberrations in the performance scores but the variation of performance scores for evacuation and registration is larger in the Westerschelde Tunnel hazardous materials scenario than in other scenarios. The outcomes of the post-exercise evaluations do not provide an explanation for why the performance of evacuation and registration varied more in this scenario and the outcome forms a point of departure for further analysis.

Other multidisciplinary subgroups were formed around the response tasks of escorting and warning and alarming the public. Escorting is done by the police in coordination with the medical emergency services and the fire services. The variation of performance scores for escorting are largest with an average range of 4 and an average standard deviation of 1.6. However, the only team with deviant performance score for escorting was team one in the Westerschelde Tunnel evacuation scenario. The police and medical emergency services performed significantly worse in this team as compared to their peers in the other teams. There are no unusual conditions in the exercise that explain this difference in performance. Warning and alarming the public was an exclusive task for the Urban hazardous materials scenario and was therefore only part of six cases. There was one team – team six – in this exercise scenario that performed significantly worse than the other teams. There are no aberrations in the exercise that explain this weak performance.

The performance scores of multidisciplinary tasks show that multidisciplinary subgroup performance varies for each scenario. There is no particular multidisciplinary task that shows largest variation in performance scores. This suggests that variation in performance is not task specific, but depends on how the emergency response task is managed by the actors involved. Similar to task and actor performance, multidisciplinary subgroup performance seems more likely to be particularly poor for some teams than particularly high. An overview of deviant multidisciplinary subgroup performance scores is given in table 5.5.

Deviant performance scores of multidisciplinary subgroups:

- Team one in the Westerschelde Tunnel evacuation scenario obtained a significantly poor performance score for escorting.
- Team six in the Urban hazardous materials scenario obtained a poor performance score for warning and alarming the public.

Table 5.5 - Deviant performance scores of multidisciplinary subgroups

5.5 On-scene command team performance

The assessment of performance at the levels of emergency response tasks, actors and multidisciplinary subgroups reveals abundant variation in performance. It is clear that different actors and subgroups of actors managed their tasks differently. The question how these differences add up to team performance, and whether some on-scene command teams performed better than others, is still open. This section presents and discusses operational emergency management performance at the level of on-scene command teams.

Some on-scene command teams performed better than others. They handled more emergency response tasks with better results. Visual comparison of the radar charts in figures 5.1 to 5.4 may already suggest that some teams have higher overall scores than others. The accumulated scores of all teams are presented in table 5.6 to provide a precise overview of the overall performance scores.

Team / scenari o	**Westerschelde Tunnel hazardous materials scenario**	**Westerschelde Tunnel evacuation scenario**	**Urban hazardous materials scenario**	**Port carbon monoxide scenario**
1	48	41	42	47
2	52	45	45	52
3	50	68	46	43
4	53	52	53	56
5	45		56	
6	46		54	

Table 5.6 - Performance scores of on-scene command teams

The scores in table 5.6 show that operational emergency management performance is not a zero-sum game. Poor or high performance scores for emergency response tasks are not necessarily compensated by performance scores obtained for other tasks. The analysis shows that teams do not only performed differently, but that some teams also perform *better* – overall – than others. The performance scores of teams involve more variation and therefore require a larger point difference to identify deviant performance scores that performance scores of response tasks and emergency response actors. Since there were only twenty teams involved in the research, deviant scores are directly identified from the overview of performance scores, without setting a specific threshold. The overall performance scores show significant variation without real outliers. An exceptional score is, again, obtained by team three of the Westerschelde Tunnel evacuation scenario. This exception is already explained in section 5.2.

The range of the performance scores is smallest in the Westerschelde Tunnel hazardous materials scenario (R = 7) and largest in the Urban hazardous materials scenario (R = 14). The performance scores are normalized to provide a better overview of the variation. The normalized performance scores of on-scene command teams are listed and ranked from highest to the lowest scoring team in table 5.7. In the Urban hazardous materials scenario, three teams perform comparatively well while three other teams performed comparatively poor, with a gap of 0.50 in between the third and fourth ranked team. In the Port carbon monoxide scenario, one team performs considerably better than others with a gap of 0.46 between the highest and second highest scoring team. The team performance scores in the Westerschelde Tunnel hazardous materials scenario are more or less equally distributed while the scores in the Westerschelde Tunnel evacuation scenario are influenced by the exceptional high score of team three (this score is corrected for the remainder of the research, see section 5.2).

Team / scenario	**Westerschelde Tunnel hazardous materials scenario**	**Westerschelde Tunnel evacuation scenario**	**Urban hazardous materials scenario**	**Port carbon monoxide scenario**
Highest performing	Team 4 (1.00)	Team 3 (1.00)	Team 5 (1.00)	Team 4 (1.00)
↓	Team 2 (0.88)	Team 4 (0.41)	Team 6 (0.86)	Team 2 (0.54)
	Team 3 (0.63)	Team 2 (0.15)	Team 4 (0.79)	Team 1 (0.31)
	Team 1 (0.38)	Team 1 (0.00)	Team 3 (0.29)	Team 3 (0.00)
	Team 6 (0.13)		Team 2 (0.21)	
Lowest performing	Team 5 (0.00)		Team 1 (0.00)	

Table 5.7 - Normalized performance scores of on-scene command teams

5.6 Face validity of performance scores: comments from post-exercise evaluations

Comments from the post-exercise evaluations are thus far only checked when deviant performance scores are obtained by actors or multidisciplinary subgroups. A comprehensive overview of comments has been created to see whether team performance scores match with the comments from post-exercise evaluations. The objective of drafting this overview is to investigate the face validity of the outcomes. The key question of the control for face validity is whether members of on-scene command teams with high performance scores are more positive about their performance than members of teams with lower performance scores.

Most attention in the post-exercise evaluations went out to how on-scene command teams operate and perform as a whole. In general, emergency response actors of teams with high performance scores seem to be satisfied with how their team performed. Positive comments about how the teams worked together and, especially, how the team dealt with the situational assessment and division of tasks were registered frequently. As commented by the fire service officer of team four in the Westerschelde Tunnel hazardous materials scenario: "*I think we really did a good job in collecting information and developing a view of the situation. And we divided the tasks right away and everyone stuck to his task. That was great*". The attention in the comments for the situational assessment is noteworthy. The police officer of team four in the Port carbon monoxide scenario remarked that: *"We took much time for the situational assessment. We didn't wait for the first on-scene command team meeting, but looked each other up in the field to get a picture of what was going on"*. Another much commented aspect in the post-exercise evaluations of high performing teams is the functioning of multidisciplinary subgroups. The police officer involved in team four in the Westerschelde Tunnel hazardous materials scenario commented that "*because the tasks were divided quickly, we could soon go and work on our own tasks. The meetings were only used to focus on multidisciplinary issues. That made them [the meetings] very efficient*". Whereas cooperation within the teams received ample attention, less attention was paid to the outcomes that were achieved. Some participants remarked that they "*took care of everything*" or that they "*wanted to reopen the tunnel as soon as possible*". Comments were also made about the fact that teams managed to "*get everyone out*". However, the focus lied on the interactions between the emergency response actors and little comments were made on the actual results achieved.

Emergency response actors in teams with low performance scores are not necessarily dissatisfied with their performance. However, it is observed regularly that emergency response actors express dissatisfaction with specific tasks. The medical emergency services of team one in the Westerschelde Tunnel evacuation scenario, for example, were dissatisfied with the rescue and transport of victims. As stated by the officer: *"it took much time for us to find out how victims were involved in the accident. We couldn't speak to the tunnel operator and the police was busy with the traffic. We just couldn't get it started"*. Other much heard comments in the post-exercise evaluations concerns the responsibility for tasks. The police officer of team two in the Urban hazardous materials scenario remarked that: "*halfway the exercise, I still had no idea who was working on that [registration]. I just started to ask that victims for names because I saw no one else doing it"*. Other comments concern other aspects of the response, like the lack of communication between specific actors. In general, the comments in the post-exercise evaluations of low performing teams seem more negative, with specific complaints about tasks and (lack of) interaction between specific response actors. However, little attention is paid to the (lack of) results achieved.

In general, the post-exercise evaluations – independent from the performance score obtained – tend to focus on aspects of emergency response processes rather than the outcomes achieved. Aspects that are frequently mentioned by both high and low performing teams are the situational assessment, the division of tasks (or lack thereof), and coordination between the right or wrong actors or multidisciplinary subgroups. How these factors relate to performance scores is discussed in the next chapters.

5.7 Relations between performance at different levels

Given the variations in performance scores at different levels of the performance assessment, the question remains whether dependencies between different levels of performance can be found. To answer this question, it is necessary to analyze the relations between performance scores at different levels. The use of radar charts serves well to show the differences in performance in detail but makes it difficult to see patterns between tasks scores and performance at more aggregate levels. To find dependencies, the correlations between performance scores at different levels of the performance assessment are calculated.

The performance scores at different levels of the performance assessment are inherently related because higher level performance scores are derived by the accumulation of lower level performance scores. Weak positive correlations between different levels of performance are therefore expected to be found between most tasks, actors, subgroups and teams. To determine whether performance at one level has an effect on another level, it is necessary to find strong and significant correlations. The strong correlations that are found between task performance and actor performance, between task performance and team performance, and between the performance scores of different actors, are discussed.

The correlations that are found between emergency response tasks and actor performance provide two main insights. First, the performance scores of actors that are involved in one or a few response tasks only, like the advisors on hazardous materials or the tunnel operator, are strongly related to their specific task scores. This is not surprising. Second, the performance scores of actors involved in multiple response tasks are often not related to performance on core tasks. The performance of the fire services, for example, is not associated with performance scores for firefighting and rescue but to scores for recovery operations. This relation is also found for the medical emergency services, of which the performance is more strongly associated with the multidisciplinary escorting task than with the core and monodisciplinary task of medical care. This implies that variation in the performance of actors does not come from variation in performance on core, monodisciplinary tasks but from variation in performance on peripheral and often multidisciplinary tasks. The strong correlation between actor performance and performance on peripheral or multidisciplinary task, indicates that actors perform consistently on their core tasks and that variation in their performance is primarily dependent upon their performance on peripheral and multidisciplinary tasks.

The correlations between performance scores of specific emergency management tasks and the performance of on-scene command teams as a whole also provides an obvious and a less obvious finding. A plausible finding is that core emergency response tasks like medical care and firefighting are relatively strongly associated with team performance. A more intriguing finding is that performance at the team-level is strongly related to performance for the rescue and measuring tasks. This is interesting because these tasks are not central to the emergency response. However, both tasks are part of the initial stages of emergency response and several other response tasks are impossible to perform without effective measuring and rescue. The dependency of the emergency response on the effective execution of initial, interdependent tasks is made visible through these correlations between performance scores at different levels. Another notable finding is the relative weak relation between the population care tasks of evacuation, shelter, and registration and team performance. Although these tasks combined form an essential part of emergency response, performance for these tasks has little effect on overall performance.

The analysis of correlations between actor performance scores and team performance scores are interesting. Team performance is strongly related to the performance of the police and medical emergency services and only very weakly with the performance of the fire services. This observation is interesting because the fire services are usually seen as the core actor of the emergency management organization. There are two plausible explanations for this finding. First, the fire services are highly capable of performing their tasks and show little variation of performance. The variation in performance of on-scene command teams as a whole is therefore primarily based on the performance of other actors whose performance varies more strongly. Second, the fire services are primarily involved in monodisciplinary tasks and are therefore unable to influence the larger emergency response organization. The medical emergency services and the police, on the other hand, are involved in a variety of multidisciplinary tasks and when they perform well they lift up the entire emergency response. The analysis of actor performance scores has shown that the performance of the fire services varies less than the performance of other actors. The first explanation is therefore plausible although the performance of the fire services does still show variation. The explanation that the police and medical emergency services are able to influence the performance of the team as a whole cannot further be explored with the available data. The findings show that, although the fire services are at the core of the emergency response organization, their performance does not make the difference between a high or low performing on-scene command team.

Besides the links between task-, actor-, and team-level performance, the mutual links between actors have been analyzed. Two outcomes stand out. An interesting outcome of the analysis is that the performance scores of the fire services are strongly associated with the performance scores of the municipality. This outcome is interesting because these actors usually do not cooperate much during operational emergency response. There are not obvious clues in our data that explain this relation. A strong correlation that can more easily be explained is that between the performance of the medical emergency services and the police. Both actors are involved in several joined tasks and high task performance is therefore of significant influence on the performance of both emergency response actors.

The analysis of interdependencies between performance at different levels of the assessment provides several interesting outcomes. Actor performance is strongly related to performance on multidisciplinary and peripheral tasks. Team performance correlates strongly with performance on initial tasks on which many other tasks are dependent and weakly with population care tasks. And team performance turns out to be closely related with the performance of the medical emergency services and the police and not with the performance of the fire services.

5.8 Conclusion

We set out to describe and analyze what variation is observed in emergency management performance. The performance assessment reveals an abundance of variation in operational emergency management performance, at all levels of our analysis. The outcomes show that individual emergency response tasks are performed with varying success, that emergency response actors perform their tasks with different success, and that on-scene command teams as a whole handle emergencies differently. Some actors and teams perform better – overall – than others. In addition to these overall trends, deviant outcomes are identified at nearly all levels of the performance assessment. These deviant outcomes are used as focus cases for in-depth inquiry in chapter seven.

Besides showing an overall trend of abundant variation, the performance assessment reveals several more specific insights in operational emergency management performance. The assessment shows that the performance scores of core emergency response tasks are more stable in general than the performance of more peripheral tasks. This means that emergency response actors perform their core tasks more consistently. The assessment also shows that variation in actor performance is associated with performance on peripheral tasks. This means that the difference between high and low performing actors primarily comes from how they manage their non-core tasks. Another significant outcome is that variation of performance scores of multidisciplinary response tasks increases with the number of emergency response actors involved in the multidisciplinary subgroup that manages the task. In other words, more actors, and therefore more multidisciplinary coordination, results in more variation in performance. The performance assessment also show that team performance is closely related to the performance of one or two initial, interdependent tasks in some scenarios and that negative aberrations are more common than positive outliers. It seems easier to fail than to excel in operational emergency management.

Chapter 6
Communication and emergency management performance

6.1 Introduction

The analysis of communication networks during emergency response is the first of two approaches to find out how emergency response actors organize their response to emergencies. The analysis aims to identify structural characteristics of communications during emergency response and to analyze how these characteristics are related to emergency management performance. The central question of this chapter is: to what extent and in what manner do emergency response actors communicate during emergency response, and how does this affect emergency management performance?

The chapter starts with the analysis of situational awareness in section 6.2 and asking whether and how emergency response actors benefit from their position within an overall emergency response communication network. Is it true that being central in a network – being in the 'thick of things' – helps actors to perform well? The analysis continues by asking whether other characteristics of an actor's position in a communication network can explain actor performance and whether the importance of an actor's position in a network changes over time. Section 6.3 focuses on emergent coordination and the relation between the presence of multidisciplinary subgroups, emergent leadership and emergency management performance. We explore whether multidisciplinary subgroups can be found in emergency response communication networks and whether the presence of subgroups is related to emergency management performance. This analysis is also performed from the perspective of individual actors to see whether being part of a multidisciplinary subgroups has an effect on actor performance. We subsequently analyze the centrality of team leaders and actors that are expected to have a coordinating role in the emergency scenarios in relation to emergency management performance. The analyses of multidisciplinary subgroups and emergent leadership are differentiated over time as well to see whether the presence of subgroups or emergent leaders is less or more important over time? The last section (6.4) presents an analysis of collective sensemaking and asks whether the *amount* of communication within a team is related to emergency management performance. The analysis continues with the questions whether specific actors or multidisciplinary subgroups benefit from the amount of communication in a team and whether it is true that teams in which few actors are responsible for most of the communications outperform teams in which all actors interact to a more or less similar degree. Section 6.4 ends with an analysis of communication network density over time in relation to emergency management performance. We conclude in section 6.5 by listing the main findings and discussing the findings that are taken along to the qualitative, in-depth analysis of emergency management processes in chapter seven.

6.2 Situational awareness and actor performance

The first part of the communication network analysis focuses on situational awareness and the position of individual actors within the networks. Situational awareness can only be obtained and maintained when actors receive sufficient information. The core notion of this approach is therefore that actors benefit from their position in a communication network as it provides them with information and increases their situational awareness. We start by analyzing the positions of individual actors within the *overall* communication networks and determining whether these positions are related to actor performance. The positions of actors are analyzed both through the amount of communication in which actors were involved and more complex characteristics of the position of actors within the networks. The second part of this section presents a dynamic approach to communication networks and analyses at what moment of emergency response it is (most) important for actors to occupy a specific position within the communication network.

Being in the 'thick of things'

The first questions asked in the analysis of communication networks is whether and how actors benefit from their overall position within a network. Is it correct that being central in a network – being in the 'thick of things' – helps actors to perform well? The analysis of communication networks departs from the hypotheses presented in chapter four. The first hypothesis describes the relation between the position of emergency response actors in overall emergency response communication networks and actor performance.

Hypothesis one: The centrality of emergency response actors in emergency response communication networks is positively associated with actor performance.

This hypothesis relates actor centrality to performance. Several of the centrality metrics discussed in chapter four are used to analyze whether actors are involved in much or little communication during emergency response. These centrality metrics are degree centrality, weighted-degree centrality, in-degree centrality, and out-degree centrality. Actor performance is assessed with the combined scores of emergency response tasks for which actors were responsible, as explained in the previous chapter.

The position of emergency response actors in the communication networks is found to vary in different ways. On average, actors communicated with 3.7 other actors, with a standard deviation of 1.4. The analysis of in- and out-degree centrality shows that variation of in-degree centrality is larger (2.7 on average, and a standard deviation of 1.8) than the variation of out-degree centrality (2.0 on average, and a standard deviation of 1.0).

This means that there is more variation in the number of actors by which individual actors are being contacted than the number of actors that are being contacted by individual actors. When duration of communication is included in the analysis through the calculation of weighted-degree centrality, the variation increases with an average weighted-degree centrality of 465 and a standard deviation of 307[9]. The size of the standard deviation indicates that the weighted-degree centrality scores of the majority of emergency response actors ranges between 158 and 772. An overview of the outcomes is given in table 6.1. The difference between the minimum and maximum degree values and standard deviations indicate that the extent in which actors are involved in communications during emergency response varies strongly.

	N	Min.	Max.	Mean	SD
Degree centrality	92	0	6	3.7	1.4
Weighted-degree centrality	92	0	1618	465	307
In-degree centrality	92	0	6	2.7	1.8
Out-degree centrality	92	0	4	2.0	1.0

Table 6.1 - Variation in actor centrality

The analysis shows thus far that there is variation in the centrality of actors within communication networks. To analyze whether actor benefit from their position, the outcomes of the centrality metrics are correlated with performance scores. This is done with normalized centrality metrics and performance scores because centrality and performance can only be compared between the same actors responding to the same emergency scenario[10]. Figure 6.1 shows the normalized weighted-degree centrality of all emergency response actors in relation to their normalized performance scores. Although it seems that the right upper corner of the graph, where observations of actors with relatively central positions in the communication networks and high performance scores end up, is more densely populated than other parts of the graph, there is no significant correlation between the two factors. Analysis of actor centrality in emergency response communication networks and actor performance does not yield significant results. The outcomes therefore do not provide support for the first hypothesis that relates centrality to performance. Being central in the overall communication network – being in the *thick of things* – is not found to explain actor performance in the emergency responses observed.

[9] The outcome of the weighted-degree centrality calculation is a combination of the number of relations between an actor and other actors and the duration of the communication with these relations (see chapter four).

[10] See section 4.4 for an explanation of normalization.

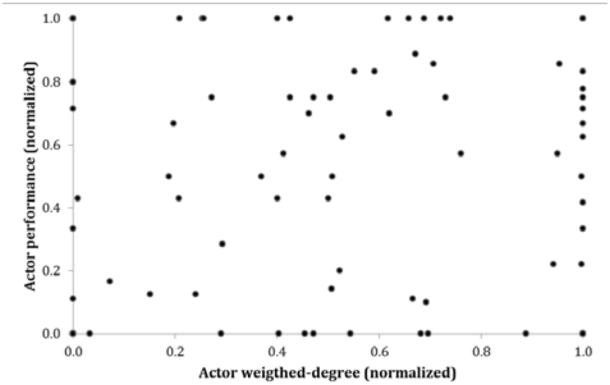


Figure 6.1 - Actor weighted-degree centrality and actor performance

Being important in a team

The analysis of actor centrality continues now it is clear that actors do not systematically benefit from being central in their emergency response communication network. Can it be that other characteristics of an actor's position in the network explain actor performance? The search for alternative explanations starts with the visualization and comparison of communication networks of actors that are likely to provide new insights. Actors that are likely to provide additional insights are those with varying outcomes on the variables of interest; centrality and performance. In line with the ideas of purposive case selection discussed in chapter four, actors with diverse outcomes are selected. Figure 6.2 shows the normalized weighted-degree centrality of emergency response actors in relation to their performance and highlights four actors with diverse outcomes on centrality and performance. One actor performs well and is central in the communication network, a second actor also performs well but is not central in the network, the third actor performs poorly and is central in the network, and the last actor performs poorly and is not central in the communication network. Together, the four actors represent the four extremes in the possible combinations between centrality and performance. The four selected cases involve the same actor; the fire services. This is done to simplify the comparison. It is not possible to keep the scenario constant as well. This is also less important since the analysis aims to find a general relation between centrality and performance, regardless of the emergency scenario that an actor is participating in.

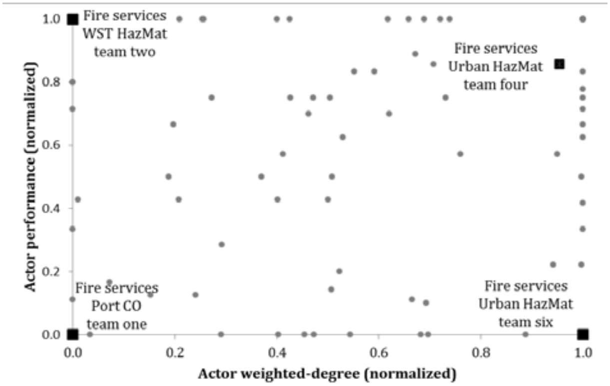


Figure 6.2 - Diverse cases of actor weighted-degree centrality and performance

The communication networks of the emergency responses in which the four selected actors were involved are visualized and compared to search for differences between the positions of the actors. The communication networks are shown in figures 6.3a to 6.3d. Comparison of the visualizations suggests that the high performing actors are more important in their network than the low performing actors. The fire services in figures 6.3a and 6.3b (the high performers) are the most dominant actors – in terms of the *amount* of communication – within their teams. The fire services in figures 6.3c and 6.3d (the low performers) are less dominant in the communication networks. The hypothesis is therefore formulated that actors that are important within a response communication network – in the sense that they communicate more than other actors within the same network – perform better than their less important peers. To analyze importance, actor centrality is compared to the average centrality of actors in a communication network. Actor positions are thereby related to the other actors in the same network and not to an actor's peers in other networks (which is done by normalizing outcomes). The outcomes of the analysis of actor importance in relation to actor performance do not yield significant results. Being important in the emergency response communication network is not systematically associated with actor performance.

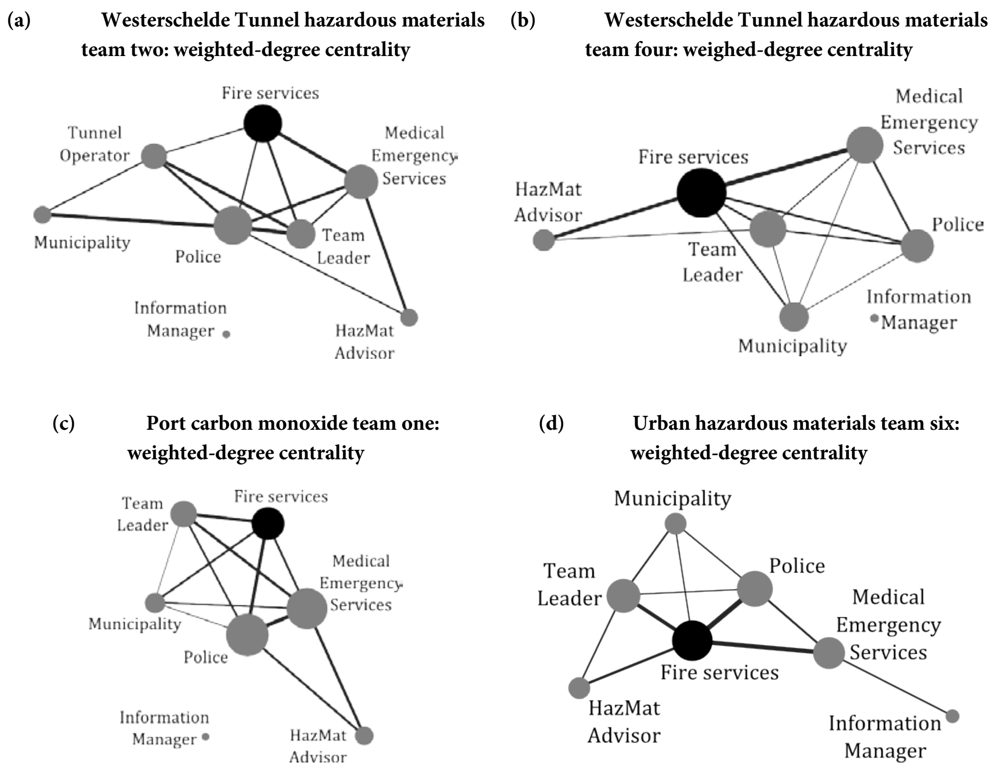


Figure 6.3 - Communication networks of diverse cases of actor weighted-degree centrality and performance

Talking with the right actors

Another potential explanation for differences between actor performance may be found in the choice of actors that an actor in question is communicating with. Communication with some actors can be functional while communication with other actors can be non-functional or distracting. It can therefore be that it is not the total amount of communication in which an actor is involved, but the amount of communication between an actor in question and a selection of functionally related actors that is associated with performance. To explore this potential explanation, it is necessary to differentiate between functional and non-functional relations between actors. Depending on the emergency scenario, communication between actors is defined as functional or non-functional. The effects of communications with functional and non-functional relations for actor performance are summarized in two working hypotheses. The first working hypothesis is that intensive communication with functional relations is necessary for an actor to perform well. The reasoning behind this hypothesis is that communication is necessary for the exchange of information and the coordination of tasks and is therefore indispensable for high performing actors. The second working hypothesis is that intensive communication with non-functional relations is associated with low performance. The thought behind this hypothesis is that communication with non-functional relations distracts actors from their tasks and keeps them from communication with functional relations and therefore decreases performance.

Network analysis is insensitive to the contents of ties and the analysis of communication networks does not involve qualitative aspects of the messages that are send between emergency response actors. It is therefore impossible to analyze whether communication is functional or not on basis of the contents of interactions. The only possibility is to determine which relations between actors are likely to be functional or not on basis of characteristics of emergency scenarios. To perform such an analysis, key actors are selected in each exercise scenario for which the functional relations are defined. Relations with other actors in the emergency response are considered as non-functional. The amount of communication that goes on in functional and non-functional relations is subsequently analyzed with support of weighted-degree centrality. The comparisons of communication networks of different exercises are made on basis of visualizations of the networks and the amount of communication that is observed between specific actors. The networks are shown in figures 4a to 4h.

Several actors with a prominent role in the Urban hazardous materials scenario are analyzed in terms of functional and non-functional relations. The medical emergency services are in charge of the medical care task, including triage of victims and deciding which victims needed medical treatment and which victims were send to the shelter location (on basis of information from the fire services). The police and municipality have important tasks in securing and evacuating the area surrounding the burning ship. The fire services – in consultation with the advisor on hazardous materials – decide on what to do with the ship and the size of the evacuation area. The fire services are selected for a more in-depth analysis of functional and non-functional ties. The fire services are chosen because they have to communicate with other actors to perform tasks successfully and simultaneously keep away from coordinating the larger emergency response and getting distracted from their own specific tasks. The fire services depend upon the advisor on hazardous materials for information about the hazardous materials, the fire, and the area to be evacuated. The fire services depend upon the medical emergency services for information about the people on the ship that need to be rescued (the medical emergency services are faster at the scene than the municipality and therefore provide this information). Other relations, between the fire services and the police, municipality, and other actors, are non-functional and potentially distracting for the fire services.

Figure 6.4a shows the field communication network of on-scene command team four in the Urban hazardous materials scenario. This fire services in this team performed best of all fire services that took part in Urban hazardous materials scenario. Figure 6.4b shows the field communication network of on-scene command team six, the fire services of this team obtained the lowest performance score in the Urban hazardous materials scenario exercises. The communication network of team four shows relations between the fire services and the advisor on hazardous materials, the municipality, the team leader, the police and the medical emergency services. The thickness of the lines between the actors represents the amount of communication registered between the actors. The graph shows that the fire services communicated intensively with the advisor on hazardous materials and the medical emergency services. The communication network of team six shows the same relations between the fire services and other actors. This time, however, the fire services communicate most with the medical emergency services, the police, and the team leader. Communication with the advisor on hazardous materials is less intensive. A comparison of the two communication networks points out that the relation between the fire services and the advisor on hazardous materials is much stronger for the high performing than for the low performing fire services. Moreover, the low performing fire services communicate intensively with the police and team leader. Both of these actors are defined as non-functional. The situation of the fire services in the Urban hazardous materials scenario provides support for the suggestion that intensive communication with functional relations is associated with high performance and that intensive communication with non-functional relations reduces performance.

Evacuation was the core emergency response task in the Westerschelde Tunnel evacuation scenario. Evacuation is primarily the responsibility of the municipality but requires support from the medical emergency services and the police when the conditions under which the evacuation takes place are difficult and there is a need to act quickly. The fire services and the tunnel operator have role in the evacuation as well. The fire services guide people from the emergency location to the safe tunnel and the tunnel operator coordinate transport towards and in the tunnel. The medical emergency services are selected as the actor to analyze in terms of functional and non-functional relations. The medical emergency services are chosen because they form a crucial link between the fire services at the emergency scene and the municipality that arranges the shelter. The medical emergency services need information from the fire services about the number of people involved in the crash and their injuries to perform well. They also need to communicate with the municipality to get people as quickly out of the tunnel as possible. Communications with other actors in the emergency response are, in general, not required. Figure 6.4c shows the field communication network of team three in the Westerschelde Tunnel evacuation scenario. The medical emergency services in this team obtained the highest performance score of the four teams that took part in this exercise scenario. The graph shows that the medical services communicate with the municipality, the team leader, the fire services, and the police. Most of the communication takes place between the medical emergency services and the fire services, although this communication is not extensive. Figure 6.4d displays the communication network of team one that obtained the lowest performance score for the medical emergency services in the Westerschelde Tunnel evacuation scenario. In this team, the medical emergency services communicate with the information manager, the municipality, the police, the fire services and the team leader. The communication is not intensive but most talk takes place between the medical emergency services and the police and the medical emergency services and the information manager.

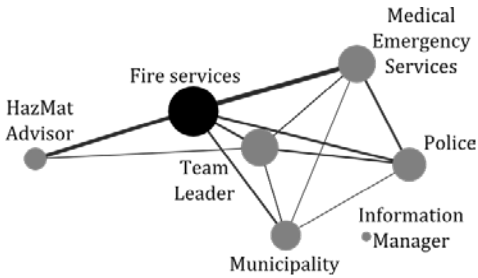
Communication between the functional relations of the medical emergency services, the municipality and the fire services, is found in both communication networks. The presence of communication with non-functional relations is also similar with exception of communication between the medical emergency services and the information manager that only occurs in the network of team one. The structure of the two networks is largely similar. The differences in the intensity of communication are not obvious. In team three, the team of the high performing medical emergency services, the medical emergency services communicate most with the fire services and the municipality although the differences in intensity with regard to the communication with the police and the team leader are small. In team one, the medical emergency services communicate most with the police. Since the police is not a functional relation of the medical emergency services in the Westerschelde Tunnel evacuation scenario, the presence of intensive communication between the two actors in team one corresponds with the expectations, given the low performance of the medical emergency services. The claim of the second working hypothesis, that intensive communication with non-functional relations hampers performance of actors during emergency response, is supported by this observation. Communication with functional relations is slightly more intensive in team three. This observation supports the idea that intensive communication with functional relations is necessary for actors to perform well. However, the differences are less apparent than in the case of the fire services in the Urban hazardous materials scenario.

The fire services are a key player in the Westerschelde Tunnel hazardous materials scenario because of the involvement of multiple hazardous materials. The fire services decide, in consultation with the advisor on hazardous materials, which actors are allowed to access the emergency scene and when emergency response tasks can be started. Other actors take care of important tasks as well, like the police who guide traffic in the surroundings of the tunnel. However, the key to a quick response, and hence a high performance score for the team, is in the hands of the fire services who have to make sure that all emergency response tasks can be started as soon as possible. The fire services are therefore chosen for the analysis of functional and non-functional communications. The fire services depend upon the tunnel operator for information about the accident and upon the medical emergency services for support regarding the rescue of victims. The fire services are a source of information for other actors, like the police and municipality, and are therefore likely to be distracted by information requests. In sum, the functional relations of the fire services in the Westerschelde Tunnel hazardous materials scenario are with the tunnel operator, the advisor on hazardous materials and the medical emergency services. Relations with other actors re non-functional and likely to be distracting and therefore qualify as non-functional. The communication network of team two, the team with the highest performing fire services in the Westerschelde Tunnel hazardous materials scenario, is shown in figure 6.4e. The fire services in this team communicate with the medical emergency services, the tunnel operator, the police, and the team leader. Most communication takes place between the fire services and the medical emergency services. Figure 6.4f shows the communication network of team one in which the fire services obtained a relatively low performance score. The fire services of this team communicate with the police, the medical emergency services, the team leader, the information manager, and the tunnel operator. Most communication of the fire services in this team takes place with the police, followed closely by communication with the medical emergency services.

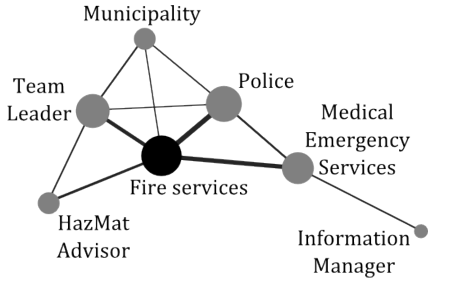
The outcomes of the analysis of communications with functional and non-functional relations of the fire services in the Westerschelde Tunnel hazardous materials scenario are mixed. The high performing fire services communicate intensively with some functional relations, but not with all. They also communicate with non-functional relations but not intensively. The low performing fire services communicate intensively with some functional relations as well. They also communicate intensively with the police, a non-functional relation. What is noteworthy about both cases is that the fire services do not communicate with the advisor on hazardous materials, despite the functionality of this relation. In case of the high performing fire services, the advisor on hazardous materials is related to the medical emergency services, another functional relation. For the low performing fire services, the advisor on hazardous materials is related to the police, a non-functional relation. What is striking about the communication network of team one, with the low performing fire services, is the intensive communication between the fire services and the police. This relation is not defined as functional on basis of the characteristics of the scenario.

The Port carbon monoxide scenario features two substantial emergency response tasks. The first task, clearing the carbon monoxide from the ship and rescuing victims, is a monodisciplinary task of the fire services. The second task, the aid and shelter of victims, is taken care of by the municipality, the medical emergency services, and the police, with possibly some support of the fire services. For the analysis of functional and non-functional ties, the municipality is chosen. The municipality has an interesting role in the Port carbon monoxide scenario. The municipality is primarily responsible for the shelter of victims that do not suffer from carbon monoxide poisoning. For the successful shelter of victims, the municipality works together with the medical emergency services that are sending non-injured victims to the shelter location. Information about the victims is given to the police who are responsible for informing the public. The functional relations of the municipality are therefore the medical emergency services and the police. Relations with other actors are seen as non-functional.

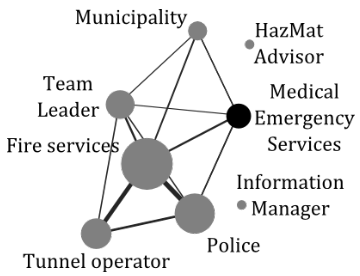
(e) **Urban hazardous materials scenario team four: high performing fire services**



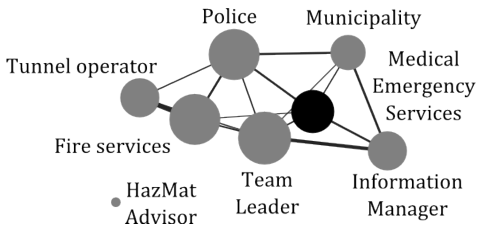
(f) **Urban hazardous materials scenario team six: low performing fire services**



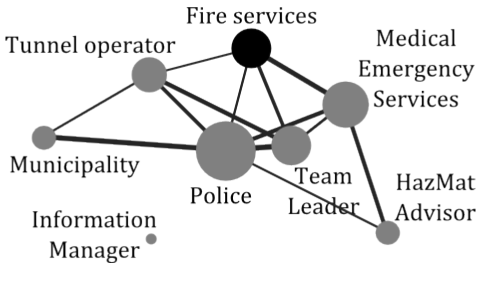
(g) **Westerschelde Tunnel evacuation scenario team three: high performing medical services**



(h) **Westerschelde Tunnel evacuation scenario team one: low performing medical services**



(i) **Westerschelde Tunnel hazardous materials scenario team two: high performing**



(j) **Westerschelde Tunnel hazardous materials scenario team one: low performing**

(k) **Port carbon monoxide scenario team four: high performing municipality**

(l) **Port carbon monoxide scenario team three: low performing municipality**

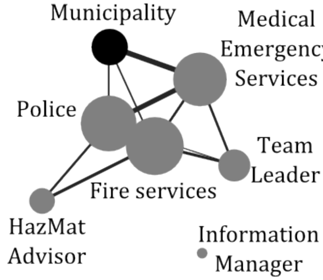


Figure 6.4 - Communication networks of diverse cases regarding actor performance

Figure 6.4g shows the communication network of team four that participated in the Port carbon monoxide scenario. The municipality in this team perform best of the four municipalities that took part in the scenario. The network shows two relations between the municipality and other actors. The municipality communicates with the police and the leader of the on scene command team. The communication is slightly more intensive with the police. Figure 6.4h shows the communication network of the third team that took part in the Port carbon monoxide scenario. The municipality in this team obtained the poorest performance score. The municipality of team three communicates with the medical emergency services, the police, and the fire services. Only the communication with the medical emergency services is intensive.

The high performing municipality of team four does not communicate with all of its functional relations. There is no communication with the medical emergency services that decide how many people need shelter from the municipality. The two actors that the municipality is communicating with, the police and the team leader, are both related to the medical emergency services. The relatively poorly performing municipality of team three is communicating with its functional relations, the medical emergency services and the police. Communication with the medical emergency services is intensive. The municipality also communicates with the fire services, a relation that is not functional in the Port carbon monoxide scenario. This communication is not intensive.

The observations about communications with functional and non-functional relations for the four core actors are summarized in table 6.2. The summarized outcomes enable us to see whether the two hypotheses about the effects of communication with functional and non-functional relations for actor performance are substantiated by the observations. Our first working hypothesis stated that intensive communication with functional relations is necessary for actors to perform well. This hypothesis would be substantiated when high performing actors communicate intensively with functional relations and low performing actors do not. Out of the four high performing actors, one – the fire services in the Urban hazardous material scenario – communicates intensively with *all* functional relations. The other high performing actors communicated intensively with several functional relations and briefly with others. Intensive communication with *all* functional relations does therefore not come out of the analysis as a necessary condition for high performance. A weaker inference, that intensive communication with several functional relations is necessary for high performance, is substantiated by the observations on high performing actors.

The second working hypothesis stated that performance of individual actors can be explained by the absence of distraction from communication with non-functional relations. This hypothesis is supported when high performing actors do not communicate intensively with non-functional relations and low performing actors do. Table 6.2 shows that none of the high performing actors communicates intensively with non-functional relations. The low performing actors do communicate extensively with non-functional actors, with exception of the poorly performing municipality in the Port carbon monoxide scenario. These findings support the second working hypothesis in the sense that abstinence from intensive communications with non-functional relations seems to be a sufficient condition for high performance but not a necessary condition for low performance. In general, the inference that intensive communication with non-functional actors has a negative effect on actor performance is supported by the observations.

The analysis also shows that the relation between communications with functional and non-functional actors is not as straight-forward as depicted beforehand. High performance is not unambiguously associated with intensive communication with functional relations. This suggests that effective communication and information exchange cannot easily be quantified and measured. This is in line with other outcomes of the communication network analysis that are discussed further on in this chapter. More clear support is found for the other hypothesis, that intensive communication with non-functional actors has a negative effect on actor performance. The absence of distraction by intensive communications with non-functional relations seems to be an important explanation for high actor performance.

	High performing actors		**Low performing actors**	
	Intensive communication with functional relations	Intensive communication with non-functional relations	Intensive communication with functional relations	Intensive communication with non-functional relations
Westerschelde Tunnel hazardous materials scenario	*Present*	*Absent*	*Present*	*Present*
Westerschelde Tunnel evacuation scenario	*Present*	*Absent*	*Absent*	*Present*
Urban hazardous materials scenario	*Present*	*Absent*	*Present*	*Present*
Port carbon monoxide scenario	*Absent*	*Absent*	*Present*	*Absent*

Table 6.2 - Communications of high and low performing actors with functional and non-functional relations

When to be in the thick of things?

The analysis of the positions of actors in the *overall* communication networks provides insights in how the *overall* ability of actors to obtain information (indicating their situational awareness) affects actor performance. Whereas the analysis provides several insights in how situational awareness relates to actor performance, the analysis also points out that *overall* communication networks are too general and high level to explain actor performance. A dynamic analysis that differentiates between three stages of emergency response is therefore performed to search for more refined insights. As explained in chapter four, our dynamic communication network analysis makes a distinction between an initial, intermediate, and final stage of emergency response. By dividing emergency response in three stages, it is possible to see whether the positions of actors and their situational awareness matters more or less at specific *stages* of emergency response and if so, when it matters most. The hypothesis that initiates the dynamic analysis of actor centrality is:

Hypothesis two: The centrality of emergency response actors in emergency response communication networks during the early stages of emergency response, and decreasing centrality in later stages of the response, are positively associated with actor performance.

The centrality of actors in the communication networks is analyzed with several centrality metrics. Most important for the test of hypothesis two are degree centrality and weighted-degree centrality because these metrics provide the best insight in the amount of communication in which an actor is involved. Actor performance is assessed through the accumulated scores of the tasks for which an actor is responsible. Whether actor centrality is increasing or decreasing over time is analyzed from an absolute and relative perspective. To obtain an absolute perspective, the centrality of actors during different stages is compared between actors of different teams. A relative perspective is obtained by analyzing the difference between centrality at different stages for specific actors.

The general outcomes of the dynamic analysis of communication networks are as follows. The centrality of actors during different stages of emergency response varies significantly, both between stages and between actors responding to the same emergency scenario. The average trend in the centrality metrics shows a decrease of communication over the course of the emergency responses. The average weighted-degree centrality[11] of emergency response actors is 285 in the initial stage, 203 in the intermediate stage, and 158 in the final stage. Actors tend to communicate most in the early stages of emergency response and the amount of communication decreases when emergency response progresses.

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[11] Weighted-degree centrality with a tuning parameter of 0.5, giving equal importance to the duration of communication and the number of actors that an actor in question is communicating with.

A first analysis aims to see whether and how actor centrality in different stages of emergency response relates to overall actor centrality. Is the overall centrality of an actor in a communication network primarily the result of its communication during the initial, the intermediate, or the final stage of emergency response? A correlation analysis provides significant and positive relations between weighted-centrality in the intermediate and final stages of the responses and overall weighted-centrality (the outcomes are shown in table 6.3). This is not surprising in itself; given the fact that overall centrality is based on centrality in the three stages combined. What is surprising is that there is no relation between overall centrality and centrality during the initial stage. While most communication takes place during the initial stage of emergency response, it is not the position of an actor within the communication network at this stage that is most relevant for the overall outcome but the position during the intermediate and final stages of the response. Communication during the intermediate and final stages of emergency response turns out to be responsible for the variation in the overall amount of communication in which actors are involved. Since actor centrality in the overall communication network cannot easily be associated with actor performance, it can now be that the centrality of actors in either the initial stage, or the later stages of emergency response is associated with actor performance.

		Actor weighted-degree centrality during the initial stage of emergency response	**Actor weighted-degree centrality during the intermediate stage of emergency response**	**Actor weighted-degree centrality during the final stage of emergency response**
Actor weighted-degree centrality	Pearson Correlation	.141	.572**	.456**
	N	92	92	92

* = P ≤ 0.05

** = P ≤ 0.01

Table 6.3 - Overall weighted-degree centrality and weighted-degree centrality in different stages of emergency response

The relative change of actor centrality in the communication networks – the differences between the stages – forms the first metric to analyze the importance of the dynamics in actor positions for actor performance. The relative change is measured with the percentage by which the weighted-degree centrality of actors changes between stages. Figure 6.5 shows the relative change of the weighted-degree centrality of actors between the initial and intermediate stage of emergency response and relates the change to normalized actor performance. The first aspect that the figure shows is that, except for some outliers that show a strong increase in weighted-degree centrality, the centrality of actors generally decreases after the initial stage. The figure also shows that this happens with high as well as low performing actors. The analysis does not provide a significant correlation between the decrease of weighted-degree centrality and performance, despite the fact that the graph suggests that high performing actors experience a strong decrease of communication more often. The relative change of actor centrality between the intermediate and final stage of emergency response is also not significantly related to actor performance. A difference between the amount of communication in the initial and the intermediate stage is not associated with actor performance and the claim of hypothesis two, that decreasing actor centrality after the initial stage of emergency response is associated with high actor performance, is not confirmed by the analysis of the dynamics in communications.

To determine whether the absolute amount of communication in which actors are involved in specific stages of emergency response is related to actor performance, a correlation analysis is performed that relates several centrality metrics from different stages of emergency response to overall actor performance. This analysis does not yield significant results for degree centrality and weighted-degree centrality in any stage of the response. The absolute amount of communication in which actors are involved in any phase of emergency response is not related to actor performance. The intermediate stage of emergency response turns out to be of critical influence on an actor's centrality in the overall communication network but the centrality of an actor during this stage of the response is not related to the actor's performance. This analysis suggest that it is not necessary for an actor to be involved in much communication during *any specific* moment of emergency response. The *amount* of communication in which an actor is involved is never a useful indicator for actor performance. The hypothesis that actor centrality in the initial stage of emergency response, and decreasing centrality in later stages of the response, is associated with performance is not supported by the observations.

Advanced metrics: being in the right place at the right time

Because the analysis of the amount of communication in which actors are involved and actor performance does not provide significant outcomes, a correlation analysis of more advanced centrality metrics is performed to see whether more complex traits of communication patterns and actor positions at specific moments of emergency response are related to actor performance. This analysis includes betweenness centrality, closeness centrality and (weighted) in- and out-degree centrality. The analysis provides several significant outcomes.

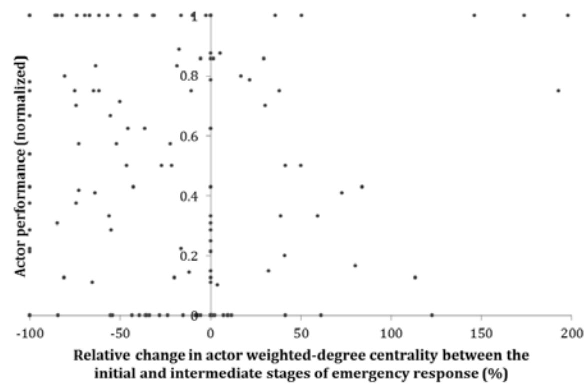


Figure 6.5 – Relative change of actor weighted-degree centrality between the initial and intermediate stage of emergency response and actor performance

Betweenness centrality of actors in the intermediate stage of emergency response is significantly (.274**) related to actor performance. Betweenness centrality is a more complex metric than degree and weighted-degree centrality and it is difficult to see the meaning of this finding right away. Betweenness centrality indicates the position of an actor in between other actors within a network. The finding therefore indicates that the particular position of an actor within the communication network is important to explain actor performance. To shed more light on what betweenness centrality in a communication network looks like, figures 6.6a to 6.6f visualize the communication networks of a particular actor – the medical emergency services – in a single scenario – the Westerschelde Tunnel hazardous materials scenario, in the intermediate stage of emergency response. The medical emergency services that participate in this scenario have varying outcomes for betweenness centrality. The size of the nodes in figures 6.6a to 6.6c is based on the actor's weighted-degree centrality. The larger the node, the *more and longer* the actor is communicating with other actors. The figures 6.6d to 6.6f show the same communication networks but the size of the nodes is now based on the *betweenness* centrality of the actors. Actors at the edges of the networks have the lowest betweenness centrality and are therefore shown with a small node. The more *in-between* other actors an actor is within the communication network, the higher its betweenness centrality and the larger the node size.

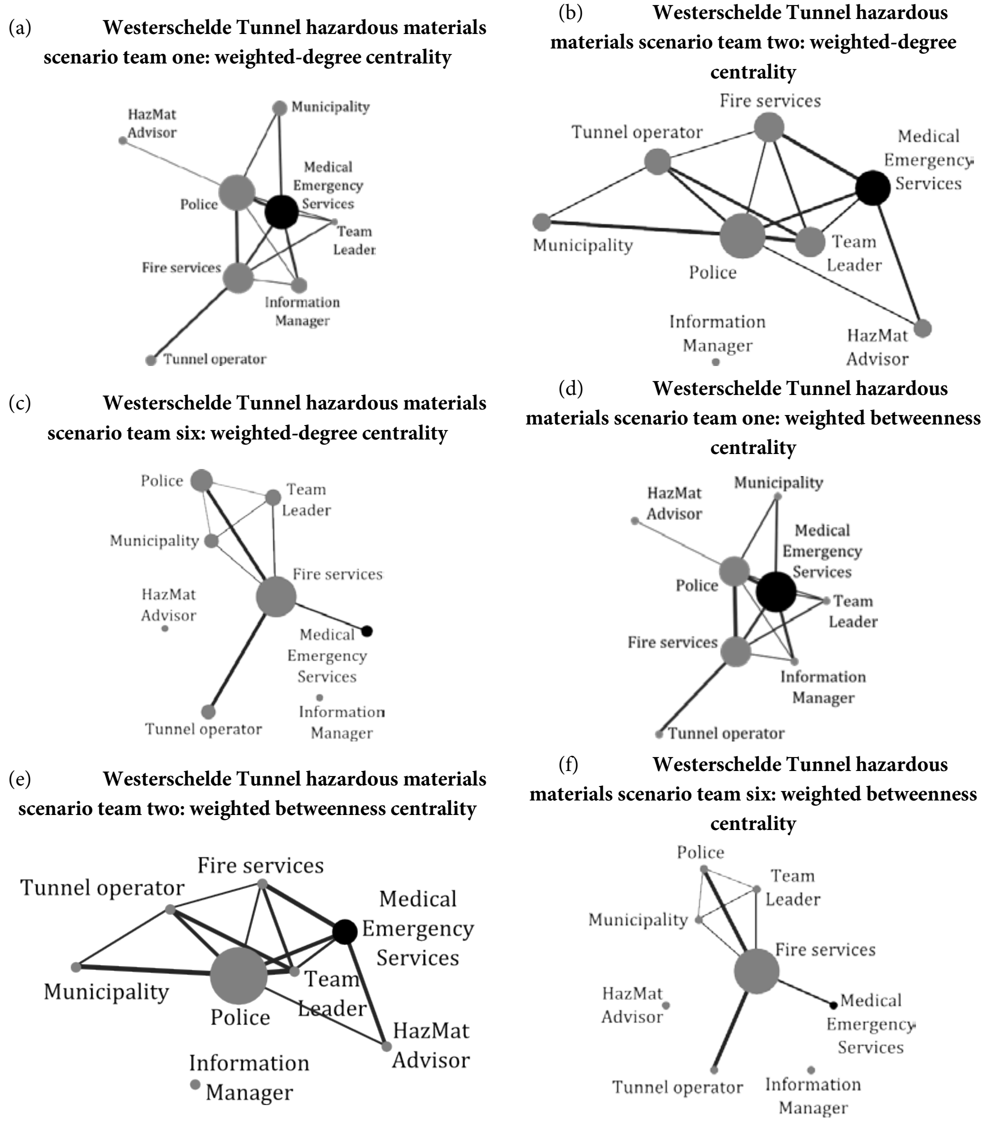
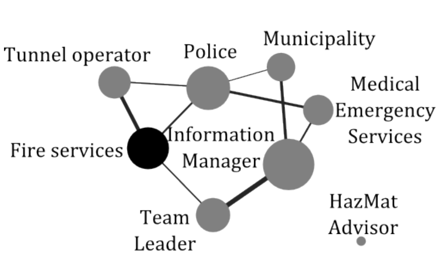


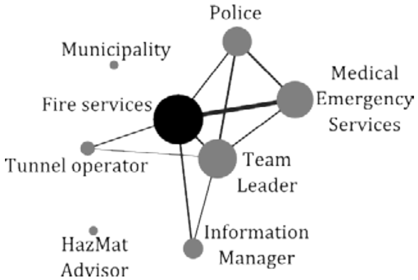
Figure 6.6 - Communication networks of the intermediate stage of emergency response to the Westerschelde Tunnel hazardous materials scenario

A comparison of the communication networks on basis of weighted-degree centrality and betweenness centrality suggests that the two metrics are related. This observation is confirmed by a correlation analysis that shows that the two metrics are significantly related (.336**). The relation between weighted-betweenness and (non-weighted) degree centrality is even stronger (.517**). This implies that, since weighted betweenness centrality (alpha 0.5) gives equal importance to the number of other actors that an actor communicates with and the length of the communication, the existence of a relation between two actors is more relevant for actor performance than the length of the communication. The finding that betweenness centrality is associated with actor performance indicates that the *position* of an actor within the communication network, and not the *amount* of communication with other actors, is most relevant for explaining actor performance.

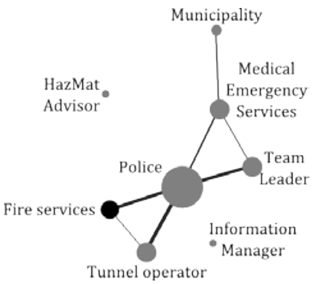
(a) **Westerschelde Tunnel evacuation scenario team one: medium weighted-degree centrality**



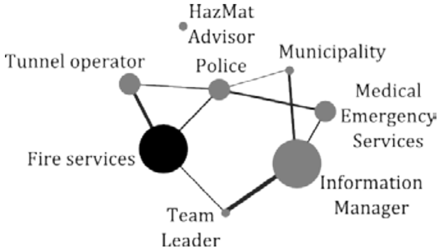
(b) **Westerschelde Tunnel evacuation scenario team two: high weighted-degree centrality**



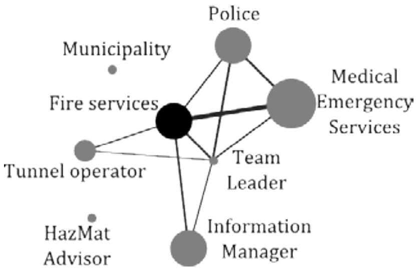
(c) **Westerschelde Tunnel evacuation scenario team three: low weighted-degree centrality**



(d) **Westerschelde Tunnel evacuation scenario team one: high in-degree**



(e) **Westerschelde Tunnel evacuation scenario team two: medium in-degree**



(f) **Westerschelde Tunnel evacuation scenario team three: low in-degree**

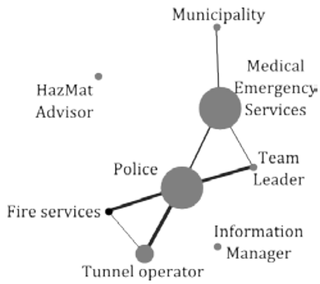


Figure 6.7 - Communication networks of the intermediate stage of emergency response to the Westerschelde Tunnel evacuation scenario

Next to the findings for betweenness centrality, the analysis provides a significant outcome for in-degree centrality. The in-degree centrality of actors – the amount of communication that is send to, or received by an actor – during the intermediate stage of emergency response is positively and significantly (.289**) related to overall actor performance. While actor degree centrality – the total *amount* of communication in which an actor is involved – is not related to actor performance at any stage of emergency response, the in-degree in the intermediate stage is. This outcome indicates that it is not the total number of relations that an actor has with other actors that is associated with high performance but the extent to which other actors come up to an actor to communicate. The in-degree is sometimes referred to as an actor's 'status' and it is this status that is significantly related with actor performance.

Figures 6.7a to 6.7c show the communication networks of teams that operated in the Westerschelde Tunnel evacuation scenario. The figures only involve communication in the intermediate stage of emergency response. The size of the nodes in these networks is based upon the weighted-degree centrality of actors, or the *total amount* of communication in which an actor is involved. Figures 6.7d to 6.7f show the same communication networks but the size of the nodes is based on the in-degree centrality, or *status* of actors. The more communication is *received* by an actor, or the higher the actor's status, the larger the node.

Comparison of the networks shows that in-degree centrality provides a different picture of the situation than weighted-degree centrality. The fire services of team one perform relatively well while the fire services in the two other teams perform relatively poorly. The graphs show that the fire services in team one receive most of the communication while the fire services in the other teams receive less information and are sending more information. The amount of communication *received* by actors in the intermediate stage of emergency response turns out to be significantly related to actor performance. The in-depth inquiry of actions and interactions between emergency response actors in the next chapter sheds on how this effect on performance comes about.

Interim conclusion

The analysis of actor positions in communication networks departed from the expectation that occupying a central position in a communication network provides actors with information, increases their situational awareness, and thereby enhances their performance. The analysis of communication networks proves that the absolute *amount* of communication in which actors are involved is not associated with performance. *B*eing involved in more communications than other actors in a team is neither a predictor of actor performance. Dissecting the exercise scenarios to identify functional and non-functional relations between actors shows that communication with specific functional actors and, more importantly, a lack of communication with non-functional actors, is associated with high performance.

Analyzing communication networks in different stages of emergency response exposes that most communication takes place at the start of the response to an emergency. The amount of communication in the intermediate stage of the response forms the best predictor of the overall amount of communication. The dynamic analysis further discloses that the *amount* of communication in which actors are involved is at no specific stage of emergency response associated with performance.

Advanced indicators of the positions of actors at specific moments of emergency response prove useful for understanding actor performance. Being positioned *in between* other actors and *receiving* information halfway an emergency response form the best predictors for actor performance. In general, the analysis of actor positions in the communication networks exposes that the *overall* communication networks and the *amount* of communication offer little insight in emergency management performance. These accumulated metrics are not sufficiently distinctive to identify relevant relations between communication and performance. More complex indicators of actor positions produce significant results for actor performance but qualitative, in-depth analysis of the actions and interactions of actors must reveal how these effects come about.

6.3 Emergent coordination and multidisciplinary task performance

The second part of the communication network analysis focuses on emergent coordination. The multi-actor, networked setting of emergency response makes it necessary for emergency response actors to organize response efforts around urgent and important tasks. This organizing includes information exchange, synchronizing tasks and directing other actors, processes that involve communication. The main premise of the communication network analysis of emergent coordination is that the role that actors play in coordination can be derived from actor involvement in communications. Coordination requires communication, and actor positions and patterns in communication networks therefore reveal how coordination takes place. The analysis starts by identifying multidisciplinary subgroups in emergency response and studying how the presence of subgroups in the networks relates to emergency management performance. This analysis continues by reviewing how being part of multidisciplinary subgroups affects actor performance. The second part of the analysis concerns formal and emergent leadership. The positions of formal leaders in field communication networks are studied to see how their presence influences team performance. Emergent leadership is subsequently studied by dissecting the exercise scenarios to find core and non-core actors and analyzing how the positions of core and non-core actors in the communication networks are associated with emergency management performance. The analyses of multidisciplinary subgroups and leadership are both performed through the *overall* communication networks and *dynamically* by differentiating between stages of emergency response.

Multidisciplinary subgroups and multidisciplinary task performance

On-scene command teams perform mono- and multidisciplinary tasks. Monodisciplinary tasks are performed by individual actors that, in general, only need information about the emergency situation to perform their tasks effectively. In contrast, multidisciplinary tasks require coordination between multiple actors. Because of the need for coordination, multidisciplinary tasks are frequently performed by multidisciplinary subgroups within an on-scene command team. To explore whether and how multidisciplinary subgroups exist during emergency response, the communication networks of on-scene command teams are subjected to cluster analysis.

There are two ways in which the formation of multidisciplinary subgroups is studied. From the perspective of on-scene command teams as a whole – the global perspective in terms of network analysis – the question is asked whether the presence of multidisciplinary subgroups in field communication networks is related to emergency management performance. From the perspective of individual emergency response actors – the local perspective in network analysis – the question is asked whether being part of a multidisciplinary subgroup is related to actor performance.

Two issues play a prominent role in the analysis of multidisciplinary subgroups. First, detecting multidisciplinary subgroups in the overall communication networks turns out to be troublesome because communication is accumulated over a long period of time. In the initial stage of an emergency, when actors gather most information, many actors communicate at least briefly with each other to exchange information. Non-weighted overall communication networks do not discriminate between these short, informative exchanges and longer, coordinative exchanges that generally occur during later stages of the response. The analysis of multidisciplinary subgroups therefore focuses on clustering during specific stages of emergency response and uses weighted indicators only. Weighted indicators are also selected to focus on coordination. To analyze whether a subgroup within a team is coordinating a multidisciplinary task or exchanging other sorts of information, it is necessary to discriminate between informative and coordinative exchanges. With no possibility to assess the contents of the exchange, there is only one indicator to make this distinction: the duration of the exchange. The assumption that is made is that coordinative exchanges require more time than informative exchanges. Coordination involves time-consuming activities like reaching agreement and confirmation on a course of action. Information exchange involves the provision and receiving of information, activities that generally require less time. The assumption will not always be correct because coordination can sometimes happen swiftly while information exchange can be time consuming. In general, however, the assumption that coordination takes up more time than information sharing is deemed plausible.

The initial question asked about multidisciplinary subgroups is whether the presence of subgroups in a communication network is related to performance. This relation is expressed in the third hypothesis introduced in chapter four:

Hypothesis three: The tendency of emergency response actors to communicate in subgroups in later stages of an emergency response is positively associated with emergency management performance regarding multidisciplinary tasks.

The components that make up this hypothesis are the presence of subgroups in a team and team performance with regard to multidisciplinary tasks. The presence of subgroups in a team is analyzed with clustering metrics. Clustering metrics can be applied at the global or on-scene command team level and the local or individual actor level. The global clustering coefficient is used to analyze the presence of subgroups in a team. The global clustering coefficient measures the number of subgroups (closed triplets) as a fraction of the number of potential subgroups (open triplets). As a result, the global clustering coefficient indicates whether actors tend to coordinate multidisciplinary tasks bilaterally or in a group of three actors or more. The clustering coefficients are calculated as a binary and weighted version. The weighted clustering coefficient involves the arithmetic mean of the duration of the communications between the actors within a specific cluster (see chapter four). Team performance with regard to multidisciplinary tasks is analyzed on basis of the performance scores for multidisciplinary tasks. Every emergency scenario that is part of the study contains several multidisciplinary tasks, some requiring two actors to work together and some requiring more than two actors to cooperate. For the analysis of multidisciplinary subgroups, the tasks that require more than two actors to cooperate are of most interest because clustering coefficients only help to distinguish communications in subgroups from bilateral communications.

The analysis of the clustering coefficients of communication networks in specific stages of emergency responses in relation to team performance yields significant results. The presence of subgroups within a team's communication network is frequently found to be negatively related to team performance on multidisciplinary tasks. Frequently, because the relation is found in the intermediate and final stages of emergency response only, and not in the initial stage of the response. The clustering coefficients in the initial stage of emergency response are structurally high, which is the result of the fact that most actors communicate with each other at the start of a response. The clustering coefficients in later stages of emergency response display more variation. The most significant findings relate to the two most substantial multidisciplinary tasks in the emergency scenarios: evacuation and recovery of disrupted infrastructures. The evacuation task is generally important halfway an emergency response while recovery operations are performed at the end of an exercise. Table 6.4 shows the correlations between the clustering coefficients and performance for evacuation in the intermediate stage and performance for recovery operations in the final stage of the response. The outcomes show that teams in which actors form tight subgroups in the intermediate or final stage of emergency response perform worse than teams without or with less strong subgroups.

The outcomes of the analysis are more or less similar for the binary global clustering coefficients and the generalized clustering coefficients. Including the duration of the communication through the generalized clustering coefficient results in a slightly stronger negative correlation with performance than the binary coefficient. The correlation between the binary clustering coefficient and performance for the evacuation task in the intermediate stage is -.269** (vs. -.318** for the generalized clustering coefficient). The correlation of the binary clustering coefficient with performance for recovery operations in the final stage of emergency response is -.302** (vs. -.369** for the generalized clustering coefficient). The presence of subgroups is found to be negatively associated with multidisciplinary task performance, indicating that more communication between actors does not result in higher performance. The hypothesis that the presence of subgroups within field communication networks is associated with better performance with regard to multidisciplinary tasks is not supported by the outcomes of the analysis. In contrast, the findings indicate that communication in subgroups hampers performance and suggest that the amount of communication is associated with difficulties in the emergency response.

		Performance of the evacuation subgroup	**Performance of the recovery operations subgroup**
Generalized global clustering coefficient of the communication network of the intermediate stage of emergency response	Pearson Correlation N	-.318** 20	
Generalized global clustering coefficient of the communication network of the final stage of emergency response	Pearson Correlation N		-.369** 20

* = P ≤ 0.05

** = P ≤ 0.01

Table 6.4 - Clustering coefficients in the intermediate stage and multidisciplinary subgroup performance

The analysis of subgroups is also approached from the perspective of individual actors. In this case, the question is not whether communication networks contain subgroups but whether an actor is part of one or more subgroups. The local clustering coefficient is used to analyze the extent to which actors are part of subgroups. The local clustering coefficient measures the number of closed triplets (three actors that are all communicating with each other) as a fraction of open triplets (three actors of which two are not communicating) in which an actor is involved. The local clustering coefficient measures the extent to which an actor coordinates in subgroups instead of through bilateral relations. Similar to the global clustering coefficient, the local clustering coefficient is calculated on a binary basis, considering all relations between actors as equal, and in a generalized version that takes the duration of communications into account. Including the duration of communication is relevant because collaborative exchanges are expected to last longer than informative exchanges between actors. The analysis of local clustering coefficients is, similar to the analysis of the global clustering coefficient and performed for individual stages of emergency response only.

The clustering coefficient is of interest for coordination of multidisciplinary tasks that involve three actors or more. The analysis is therefore only performed with regard to tasks that involve three actors or more: evacuation and recovery operations. A correlation analysis is performed to see whether the local clustering coefficient of actors involved in evacuation and recovery operations relates to performance of these two tasks in different stages of emergency response. The analysis yields two significant outcomes that are shown in table 6.5.

		Actor performance regarding evacuation	**Actor performance regarding recovery operations**
Generalized local clustering coefficient of the actors involved in evacuation during the intermediate stage of emergency response	Pearson Correlation N	-.328** 97	
Generalized local clustering coefficient of the actors involved in recovery operations during the final stage of emergency response	Pearson Correlation N		-.279* 50

* = P ≤ 0.05

** = P ≤ 0.01

Table 6.5 - Clustering coefficients and multidisciplinary subgroup performance

The first outcome is that the local clustering coefficients of actors involved in evacuation is negatively related to their performance with regard of this task. When actors that are part of the evacuation subgroup are more involved in tightly related subgroups, their performance decreases. This finding stems from the intermediate stage of emergency response in which evacuation is most urgent. A similar finding is obtained with regard to recovery operations. The clustering coefficients of actors involved in this multidisciplinary tasks are negatively related to the performance score for this task in the final stage of emergency response. As recovery is done in the last stage of the response, this timing does not come as a surprise. What is more striking is that in both cases the relationship has the opposite direction of what is expected. Being part of connected subgroups is negatively associated with the performance of actors with regard to multidisciplinary tasks. Table 6.5 shows the generalized local clustering coefficients of the actors involved in multidisciplinary tasks in relation to task performance. The binary clustering coefficients are calculated as well and show similar but slightly weaker and less significant correlations. This implies that the duration of communication invigorates the observed relation. The more communication goes on in the subgroup of which actors are part, the lower their performance.

Formal and emergent leadership

Multidisciplinary emergency response tasks require organizing and coordination to be performed effectively. Monodisciplinary response tasks often require synchronization with other tasks as well. Since coordination and synchronization of tasks requires communication, emergence response actors have to obtain a good position in emergency response communication networks to perform their mono- and multidisciplinary tasks effectively. Having a good position is most important for actors that play a leading role in an emergency scenario. Our analysis of leadership starts by exploring the positions of formal on-scene command team leaders in field communication networks and relating their positions to team performance. The second part of the analysis concerns the positions of other emergency response actors that might present themselves as emergent leaders and relates their presence and the distribution of emergent leadership within on-scene command teams to team performance.

On-scene command teams are formally headed by a team leader. Team leaders chair team meetings and have the final say over decisions but have no formal role in the emergency response in the field. However, team leaders frequently joined the field response in the exercises. A specific analysis of the positions of team leaders in communication networks is performed to find out whether the presence and position of formal leaders in the field influences team performance. The analysis of team leader positions in the communication networks and team performance consists of two parts. First, the centrality of team leaders is explored to see whether a relation between leader position and team performance can be found. And second, the outcomes are differentiated over time to see whether team leader positions matter at particular moments of emergency response.

The analysis includes the same components as the analysis of the influence of other actor's positions on actor performance. Team leader centrality is analyzed with degree centrality, weighted-degree centrality, betweenness centrality, and closeness centrality. Degree centrality is also differentiated in in- and out-degree centrality. Team leader performance is assessed on basis of the accumulated scores of the team because team leaders are responsible for the overall response. The analysis of team leader centrality in the overall communication networks and team performance does not produce significant outcomes. The position of team leaders in the *overall* field communication networks is not associated with team performance.

The position of team leaders in the communication network is also analyzed over time by distinguishing between an initial, intermediate, and final stage of emergency response. The same centrality metrics are used as in the analysis of leader positions in the overall communication networks. The analysis of the position of team leaders in relation to team performance in different stages of the response provides one significant finding. Weighted-degree centrality of team leaders in the field communication network of the final stage of emergency response is positively and significantly related to team performance (.603*). The correlation has higher significance for in-degree centrality (.537**). These outcomes indicate that the 'status' of team leaders in the final stage of emergency response is strongly related to team performance. Teams in which many actors contact the team leader in the final stage of the response perform well. There is no obvious explanation for this finding and possible reasons behind the relation between team leader status in the final stage of the response and team performance are discussed in the next chapter.

While the position of formal team leaders in the field communication networks is not found to make a difference for team performance, emergent leadership is still expected to play a significant role. To identify the presence, and analyze the importance of emergent leadership, each scenario is dissected to determine which actors are likely to have a substantial coordinating role. The outcomes of this analysis are verified by comparing the networks of high and low performing teams in each scenario. The analysis is revisited when these networks show different patterns. Actors are subsequently divided in two groups. One group consists of actors that are supposed to become emergent leaders and whose centrality in the communication networks is expected to be positively associated with team performance. And another group of actors that are not expected to have a coordinating role in the emergency response and whose centrality is expected to be negatively associated with team performance. The centrality of the actors in both groups is subsequently correlated with team performance. The next paragraphs discuss the role of different actors in the four scenarios and describe how actors that are likely to become emergent leaders are selected.

It can be argued that the fire services are the most crucial actor in the Westerschelde Tunnel hazardous materials scenario. Primarily because the fire services are responsible for providing information to other actors in the emergency response. However, the role of the fire services in *coordinating* the emergency response is unlikely to be substantial because the fire services have a substantial set of monodisciplinary tasks to take care of. Other actors have multiple tasks to perform as well. Multidisciplinary tasks are performed by the tunnel operator, the medical emergency services, the police, and the municipality. Coordination of these tasks is done by the involved disciplines themselves or by the formal leader in case he is involved in the emergency response in the field. The characteristics of the Westerschelde Tunnel hazardous materials scenario make it more likely that a central position of the medical emergency services, the police, or the municipality is associated with high performance. These actors are involved in the important multidisciplinary tasks but are not completely preoccupied by their monodisciplinary tasks. High centrality of the fire services or one of the other actors is not expected to relate to high team performance because these actors either have to focus on their own tasks or are not involved in multidisciplinary tasks. The assumed division of emergent leadership over the different actors is first verified by visualizing and comparing the networks of high and low performing teams. The networks used for the comparison are based on weighted-degree centrality. The size of the nodes corresponds with the weighted-degree centrality of the actors. Weighted-degree centrality is chosen because it provides the best indicator of the *amount* of communication in which actors are involved. The thickness of the ties between the actors in the networks is based on the total length of the interactions.

Figure 6.8a shows the communication network of team five that performs relatively low. The fire services are the most central actor in this network. Figure 6.8b shows the network of team four that performs relatively well. In this network, the medical emergency services are the central actor. The formal leaders of both teams occupy a similar position in the communication networks of both teams. The assumption that high centrality of the fire services leads to lower performance is supported by these observations. The medical emergency services and the police are selected as potential emergent leaders in the Westerschelde Tunnel hazardous materials exercises while the fire services are listed as inapt for emergent leadership.

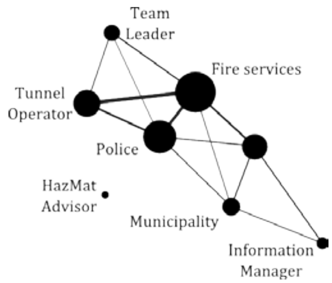
In the Urban hazardous materials scenario, the fire services are important for providing information to other disciplines and the police and municipality are responsible for the substantive task of evacuating the area surrounding the burning ship. Given the responsibility of the fire services for the monodisciplinary tasks of firefighting and the rescuing of people from the ship, the fire services are unlikely to become the central coordinating actor for the entire emergency response. Most coordination is required with regard to the evacuation of inhabitants of the surrounding area and the shelter of passengers from the ship. These tasks are primarily taken care of by the municipality and the police. These actors are therefore expected to be central in the communication networks of high performing teams. Evacuation and arranging shelter requires substantial coordination that can also be guided by the formal team leader if he or she gets involved in the emergency response in the field. Given these characteristics of the Urban hazardous materials scenario, an effective response is expected when either the municipality, the police, or the team leader is central in the communication network. Centrality of the fire services, medical emergency services or other actors is not expected to be associated with high performance. These assumptions are verified by comparing the communication networks of high and low performing teams. Figure 6.8c shows the communication network of team one, the lowest performing team that took part in the Urban hazardous materials scenario. The medical emergency services are the most central actor within this team with the police in second place. The municipality, the fire services, and the team leader occupy less central positions. Figure 6.8d shows the communication network of team five that is most successful in the same scenario. In this team, the fire services occupy a central position together with the police. The fire services interact mostly with the team leader and the police. The police is communicating most with the fire services, the medical emergency services, and the municipality. These observations are more or less in line with the expected positions of central actors. In the low performing team, the medical emergency services take the lead. The police and the municipality, the crucial actors for the evacuation, play a less prominent part. In the communication network of the high performing team, the police occupies a central spot, right in between the municipality and the medical emergency services. The fire services are central as well but their centrality is mainly due to communications with the formal team leader and the police. Whereas the medical emergency services are at the center of the low performing team, the police is the key actor in the high performing team. The position of the fire services in high performing team five is unexpected. The fire services are therefore removed from the list of actors whose centrality is expected to be associated with low performance and the role of the fire services is highlighted for further inquiry in the video-observations.

As indicated by its name, the Westerschelde Tunnel evacuation scenario is all about the evacuation of victims from the Westerschelde Tunnel. An evacuation of the tunnel is formally coordinated by the municipality. In practice, however, municipal officers arrive relatively late at an emergency scene and the evacuation is coordinated by the police in cooperation with the medical emergency services. Because some passengers are trapped or left in the closed incident-tunnel, the fire services are also part of the evacuating subgroup in the scenario. For an evacuation to be successful, it is likely that either the municipality or the police has to take the lead over the emergency response with relations to the fire services and the medical emergency services. Alternatively, the formal team leader can take the lead in the decentral response. In this case, relations between the team leader and all other emergency response actors are needed. The tunnel operator is of less importance in this scenario than in the Westerschelde Tunnel hazardous materials scenario because his tasks are limited to providing information to the fire services and organizing salvage and recovery operations. Figure 6.8e shows the communication network of the first team that took part in the Westerschelde Tunnel evacuation scenario. This team performed relatively poorly. Figure 6.8f shows the communication network of team three that performed particularly well. The fire services occupy a central position in the communication network of the high performing team. This is not in line with the expectation that the fire services are only supportive to the response effort and do not coordinate the evacuation process. In the communication network of team one, the fire services, the police, and the team leader occupy positions of more or less equal importance. What is noteworthy as well is that the municipality has a more central position in the network compared to the municipality of team three. The idea that the municipality and the police are the key actors to coordinate the evacuation does not seem to hold. The other possibility, that the formal team leader coordinates the evacuation, is neither reflected by the networks of these two teams. No specific actors from the Westerschelde Tunnel evacuation are therefore included in the analysis of emergent leadership and the role of emergent leadership is moved forward to the qualitative inquiry on basis of video-observations.

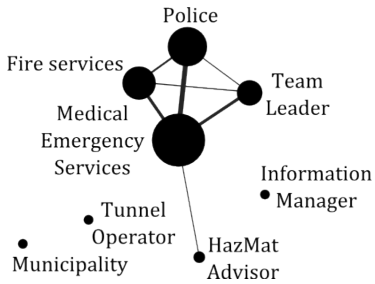
The Port carbon monoxide scenario stars the medical emergency services as the core actor. The situation on board and in the surroundings of the ship results in a large number of victims that need medical care or at least a medical check before they can be brought to the shelter location that is arranged by the municipality. The fire services are responsible for the carbon monoxide leakage at the ship and the rescue of victims. These are both monodisciplinary tasks and the fire services are not expected to be central in the rescue effort. Rescue and shelter of victims is done by the medical emergency services, the police, and the municipality together. The medical emergency services are expected to be central in this effort because they have to decide what happens to the victims. Because triage and medical care are both substantive tasks, an alternative for coordination is that the formal team leader steps in to guide the evacuation and shelter. Figure 6.8g shows the communication network of team three in the Port carbon monoxide scenario, the team that performed relatively poorly. The communication network shows that the fire services occupy a central position in the response, closely followed by the police and the medical emergency services. Communication occurs between nearly all actors involved in the response, primarily among the traditional emergency services and the municipality. Figure 6.8h shows the communication network of team four, the most successful team that took part in the Port carbon monoxide scenario. The fire services are also at the core of this network. However, much of the centrality of the fire services is due to their communications with the advisor on hazardous materials. If this interaction is excluded, the fire services become less important and the medical emergency services become the most central actor. The medical emergency services form the core of a network between the police, fire services, and the team leader. The team leader and the police are both closely connected to the municipality. The two networks suggest some differences in coordination patterns. Team three shows a more or less equal distribution of communication between important actors involved in the response. The network of team four shows a cluster of the medical emergency services, the police, and the municipality. The expected situation that the medical emergency services need to be central in the communication network for a team to be effective is supported by these two cases. The actors are therefore included in the analysis of emergent leadership and team performance.

Low performing teams	High performing teams

(a) **Westerschelde Tunnel hazardous materials scenario team five**



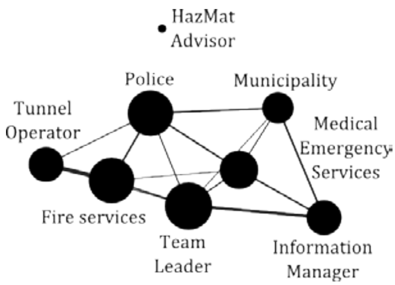
(b) **Westerschelde Tunnel hazardous materials scenario team four**



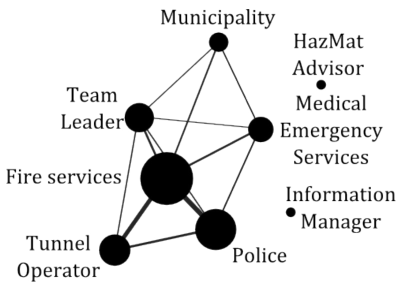
(c) **Urban hazardous materials scenario team one**

(d) **Urban hazardous materials scenario team five**

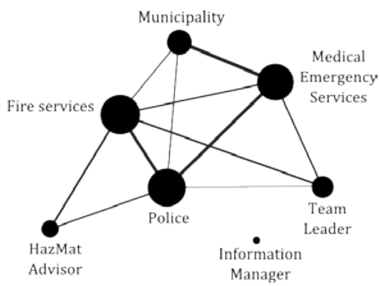
(e) **Westerschelde Tunnel evacuation scenario team one**



(f) **Westerschelde Tunnel evacuation scenario team three**



(g) **Port carbon monoxide scenario team three**



(h) **Port carbon monoxide scenario team four**

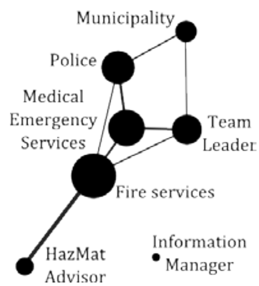


Figure 6.8 - Communication networks of high and low performing teams

A correlation analysis is performed to see whether a relation can be found between the centrality of actors that are expected to have a coordinating role in the response on basis of characteristics of the emergency scenarios and team performance. The opposite question, whether a central positon of actors that are not expected to play a significant part on basis of the characteristics of the scenarios, is also tested. The analysis does not provide a significant outcome for the centrality of expected emergent leaders. Teams in which actors with an important role in the emergency response occupy a central position in the communication network do not perform structurally better than other teams. The analysis shows a significant negative relation (-.354*) between the centrality of actors that do not play an important part in the scenarios and team performance. This outcome indicates that emergent leadership by non-core actors hampers team performance.

Interim conclusion

Prior to the analysis of multidisciplinary subgroups, the assumption was made that coordination requires more communication than information exchange and prolonged communications are therefore a proxy for coordination while short communications are expected to be primarily informative. The outcomes of our analysis indicate that the duration of communications in multidisciplinary subgroups is negatively associated with performance of multidisciplinary tasks. Prolonged communications result in lower performance, at the level of individual emergency response actors and at the level of on-scene command teams as a whole. This outcome does not support our initial line of reasoning that more communication implies more coordination, and more coordination leads to higher performance on multidisciplinary tasks. Long lasting communications seem to be associated with difficulties in coordination and therefore lower performance. This insight returns in the next chapter when qualitative observations on coordination in subgroups are presented.

Our analysis of the positions of formal team leaders in communication networks reveals that team leader centrality has no significant effect on team performance. The analysis of emergent leaders points out that emergent leadership by non-core actors hampers team performance. A central position of core actors in the communication networks does not systematically lead to higher team performance. Differentiation of the analysis of multidisciplinary subgroups and the positions of leaders over time does not provide additional insights.

6.4 Collective sensemaking and on-scene command team performance

Collective sensemaking thrives on communication because it requires the exchange and spread of information. The amount of communication between emergency response actors is therefore seen as an indicator of collective sensemaking and a main contributor to emergency management performance. The amount of field communication by on-scene command teams is analyzed with several indicators, both for the response as a whole and differentiated for more specific stages of emergency response. The outcomes of the overall analysis are presented first, followed by the results of the dynamic analysis.

The effects of talking much

The first question that is asked in the analysis of collective sensemaking is whether the overall *amount* of communication within a team is related to performance at the team-level. This question forms the first step in the analysis of communication networks at the network level. The initial analysis is guided by the fourth hypothesis formulated in chapter four:

Hypothesis four: The density of emergency response communication networks is positively associated with emergency management performance.

This hypothesis consists of two components: the amount of communication within a team and team performance. The amount of communication within a team is assessed with two communication network metrics: network density and weighted network density. Communication network density measures the number of interactions as a fraction of the maximum possible number of interactions between the emergency response actors in a given emergency response. The communication network is said to be complete when all actors communicate with all other actors on at least one moment during the emergency response. In this situation, the network density of an on-scene command teams is 1.0. In contrast, when none of the actors in the emergency response communicate with another actor, the network density is 0.0. The second metric, weighted communication network density, also measures the observed interaction as a fraction of the maximum possible amount of interaction but includes the duration of the interactions as well. Weighted-density only reaches a value of one when all actors are communicating during the entire emergency response. The two density metrics provide different indicators of the amount of communication during emergency response. Communication network density is a structural metric that indicates how many actors communicate with each other. Weighted-density provides a more gradual measure of the amount of communication between emergency response actors. The two metrics are used together to analyze the amount of field communication between actors of on-scene command teams. Emergency management performance is assessed with the performance scores of on-scene command teams as a whole. Team performance is scored by adding the performance scores of a team on all mono and multidisciplinary tasks that are part of an emergency response scenario. Network density, weighted-density of networks, and team performance re normalized to enable a comparison between teams that took part in different scenarios (as explained in chapter four).

The network density of the communication networks of the twenty on-scene command teams studied, varies between 0.16 and 0.34 with an average of 0.25. This means that in one of the teams, one-third of all actors communicate with each other while in another team this is less than one-sixth. The standard variation of network density is 0.05, indicating that the majority of the teams have a communication network density between 0.20 and 0.30. Variation of weighted network density is larger. The lowest calculated weighted network density is 0.05 and the highest is 0.29, with an average of 0.12. The standard deviation of weighted network density is 0.05, indicating that the majority of the teams has a weighted communication network density between 0.07 and 0.17. The low values for weighted network density imply that the amount of time spend on communications between emergency response actors is relatively low as compared to the amount of time spend on other performing tasks. Actors are busy with their tasks most of the time and communication comprises 12% of the available time on average.

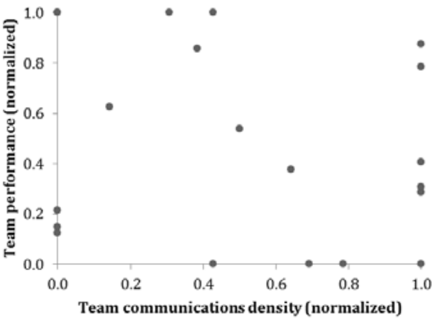


Figure 6.9 - Team communications density and performance

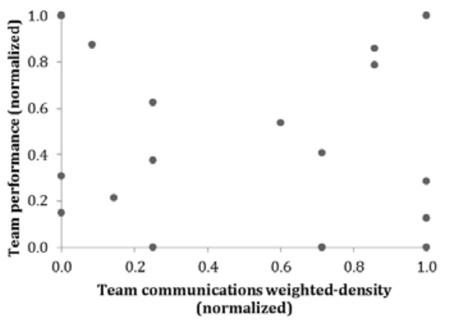


Figure 6.10 - Team communications weighted-density and performance

Because communication is necessary to obtain information and to coordinate common tasks, the amount of communication during emergency response is generally believed to be positively associated with emergency management performance. However, the outcomes of the communication network analysis of on-scene command teams do not offer support for this supposition.

Analysis of network density metrics and team performance does not yield any significant results. Figure 6.9 shows communication network density of the teams in relation to team performance. The spread of the scores confirms the lack of correlation. Communication network density – the fraction of actors that communicated with other actors – is not found to be related to team performance. Figure 6.10 shows the weighted network density of the teams in relation to team performance. The spread of the outcomes is comparable to that of non-weighted network density in relation to team performance and no significant correlation is found for this metric either. Teams in which the actors communicate more – in the sense that they interacted with more other actors and for a longer time – do not perform better than teams in which actors communicate less. The claim of hypothesis four – that the amount of communication between the actors of an on-scene command team is positively associated with emergency management performance – is therefore not confirmed by the findings of this study. Teams that communicate more – overall – do not perform better than teams that communicate less.

The analysis does not reveal a significant difference between the results of network density and weighted network density. Incorporating the duration of the communication between actors does not provide more insights than the registration of communication as being present or not. The outcomes of both metrics are positively and significantly related. This implies that there is no systematic distinction between short interactions with many other actors and long interactions with a few other actors. Communicating with more actors is systematically associated with talking longer and vice versa. This is interesting because it means that there is no suggestion that some actors communicate effectively with many other actors while other actors get stuck in long conversations or conflicts with specific other actors. This insight is further addressed in the next chapter.

The hypothesized relation between communications between actors of on-scene command teams and team performance is not confirmed by the research findings. Several other possible relations are tested as well. Most importantly whether specific actors or multidisciplinary subgroups benefit from the overall amount of communication. Because communication is deemed necessary for the spread of information and the coordination of tasks, actors that rely strongly on information are assumed to benefit more from communication than others. At the same time, actors that do not need much information to perform their tasks can be distracted by intensive information exchange. Our analysis does not provide significant outcomes that support these expectations. The overall amount of communication between actors in on-scene command teams is not associated with emergency management performance.

Talkers and workers: variation in degree centrality

Although no relation is found between the overall *amount* of field communication by on-scene command teams and team performance, other characteristics of overall team communication networks can exist that help to explain team performance. To search for alternative patterns, several teams are selected that are likely to provide alternative insights. As chapter four explains, purposive selection of cases is useful for the exploration of alternative explanations and can be done on basis of various criteria. As no relation is found between the amount of communication and emergency management performance, the search for explanations is still completely open. In such an open situation, it is useful to study diverse cases – cases with (strong) variation on the variables of interest – to search for alternative explanations. Our variables of interest are communication and team performance. Weighted communication network density is used to include the most comprehensive indicator of the amount of communication. Figure 6.11 shows team weighted communication density and team performance and highlights four teams of which the amount of communication and performance varies significantly. Teams five and six in the Urban hazardous materials scenario are selected as teams that performed well.

Team two in the Westerschelde Tunnel evacuation scenario and team three in the Port carbon monoxide scenario are selected as poorly performing teams. The other variable of interest is communication. Team five in the Urban hazardous materials scenario and team two in the Westerschelde Tunnel evacuation scenario both have communication networks with low weighted-density while team six in the Urban hazardous materials scenario and team three in the Port carbon monoxide scenario both have dense communication networks. The fact that the selected cases include different scenarios does not matter at this point as the exploration is aimed at general patterns between team communication and performance – patterns that are independent from the specific characteristics of a scenario. The structures of the communication networks of the four selected teams are explored in search for alternative explanations of emergency management performance.

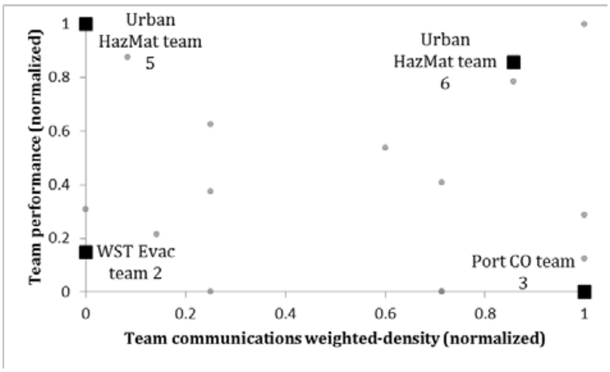
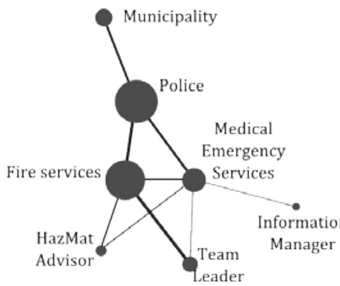


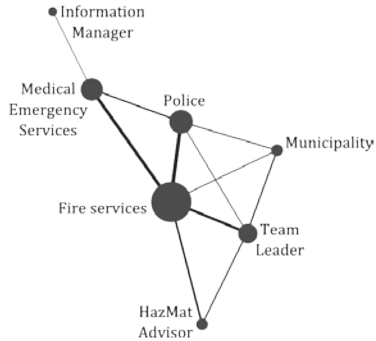
Figure 6.11 - Diverse cases of team communication network weighted-density and performance

Figures 6.12a to 6.12d show the communication networks of the four teams that are selected because of their variation in performance and weighted communication density. The thickness of the lines between the actors in the graphs varies in accordance with the duration of the communications between the actors. The longer the communications, the thicker the line. The size of the circles that symbolize the actors varies in accordance with the weighted-degree centrality of the actors. Weighted-degree centrality is included in the analysis to show which actors are responsible for which part of the communication that takes place within a team. The more interactions an actor has, and the longer the interactions last, the higher the weighted-degree and the larger the node. By including the duration of communication in the size and thickness of nodes and ties, the visualization of the communication networks makes it possible to compare the communication network structures of different teams.

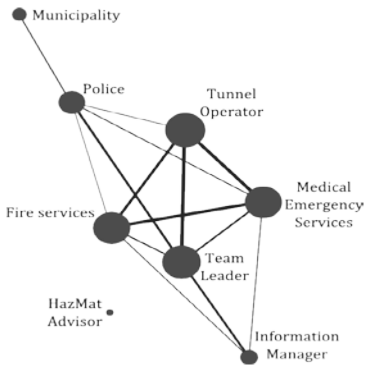
(a) Urban hazardous materials scenario team five (high performance / low density)



(b) Urban hazardous materials scenario team six (high performance / high density)



(c) Westerschelde Tunnel evacuation scenario team two (low performance / low density)



(d) Port carbon monoxide scenario team three (low performance / high density)

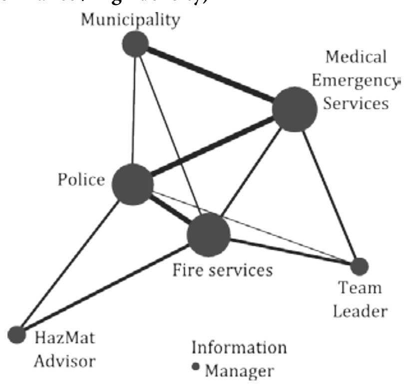


Figure 6.12 - Communication networks of diverse cases on network density and team performance

A significant difference is observed between the weighted-degree centrality of actors within different communication networks. The actors in the low performing teams – team two in the Westerschelde Tunnel evacuation scenario and team three in the Port carbon monoxide scenario – have a more similar weighted-degree centrality, as indicated by the relatively equal distribution of node sizes. The weighted-degree centrality of actors in the high performing teams – teams five and six of the Urban hazardous materials scenario – shows more variation. This observation suggests an alternative explanation for variation in team performance: variation of actor centrality within a communication network is positively associated with team performance. It may be that teams in which few actors are responsible for a large part of the communication (talkers) while other mainly work without communicating (workers) outperform teams in which all actors interact to a more or less similar degree. This hypothesis can be tested with the available data. To test whether the variation of actor centrality is associated with team performance, the standard deviations of the weighted-degree centrality of actors within teams are correlated with team performance. The outcome of this analysis is shown in figure 6.13.

The graph in figure 6.13 seems to indicate a relation between variation in actor degree centrality within a team and team performance. Increasing variation in degree centrality in the teams (higher standard deviations) seems to correlate with increasing team performance (with the exception of the two cases in the upper left corner that have relatively little variation in degree centrality and perform relatively high). However, the correlation is not found to be significant, even when the two deviant cases are excluded.

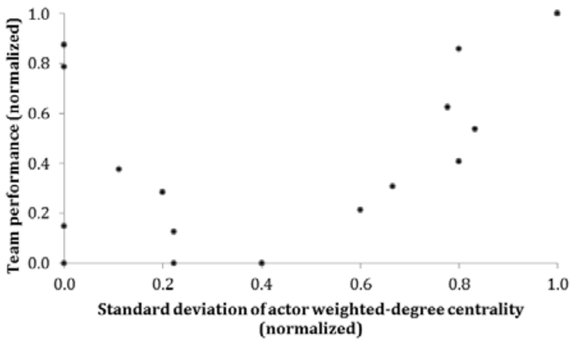


Figure 6.13 - Variety of degree centrality and team performance

It is worth mentioning that one of the deviant cases is team five of the Urban hazardous materials scenario, one of the cases that led to the initial formulation of this alternative explanation. The fact that the variation of degree centrality in this team turns out to be relatively low, but is high during visual comparison of the network graphs, indicates that the variation of degree centrality in other teams that took part in the Urban hazardous materials scenario is even larger. This implies that the relation between variation of degree centrality within a team and team performance is also subject to characteristics of the exercise scenarios. In some scenarios, it is more important for a team to have variation in the extent in which actors are involved in communication than in other scenarios. This observation returns in the next chapter when information exchange in different scenarios is discussed.

Dynamics of communication networks

Chapter four explains how collective sensemaking is often thought to be crucial to emergency management performance. To make sense of emergency situations, emergency responders need to obtain and share information. The sooner a team obtains and shares information, the sooner it can assess the situation and start a response. This line of reasoning implies that communication between emergency response actors is highly important at the start of an emergency response. The analysis of communication network density in relation to team performance is differentiated for different stages of emergency response to see whether these thoughts are correct. The differentiation of stages is again done by distinguishing between an initial, intermediate and final stage of emergency response. The dynamic analysis is guided by the fifth hypothesis formulated in chapter four:

Hypothesis five: The density of emergency response communication networks during the early stages of emergency response, and decreasing density in later stages of the response, are positively associated with emergency management performance.

The hypothesis consists of the same components that make up the fourth hypothesis that addresses the relation between the *overall* amount of communication and performance. This time the relation is differentiated over time, describing a dynamic pattern between communication density and team performance over three stages of emergency response. During the initial stage, communication within a team is supposed to be dense for a team to perform well. The density of communication is determined by measuring the network density and weighted network density and by comparing the values of different teams. The change of density over time is analyzed by comparing the amount of communication in different stages and calculating the relative increase or decrease. By considering both the absolute amount of communication and change in the amount of communication between different stages, a complete view of the communication density of different stages is obtained. The outcomes of the dynamic communication network analysis are related to team performance to see whether the proposed relation can be observed.

The network density and weighted network density of communication networks is largest in the initial stage of emergency response. The average network density in the initial stage is 0.16 with standard deviation of 0.04. The average weighted network density is 0.13 with a standard deviation of 0.06. The network density of nearly all teams decreases over the three stages, indicating that most communications take place during the initial stage of emergency response. The average decrease of network density between the initial and intermediate stage of emergency response is -13.7% with a standard deviation of 33%. The average decrease of weighted network density is -15.6% with a standard deviation of 50%. The size of the standard deviation indicates a strong variety in the change of network density after the initial stage of emergency response. Although the majority of the teams experience a decrease of communication after the initial stage, some teams register an increase of communication.

The independent intermediate stage

An analysis of the density and weighted-density of communication networks in different emergency response stages shows that the levels of communication in a team are related. This is no surprise because the time or period specific density metrics add up to determine overall density but differences between the correlation values of different stages attract attention. The strongest correlation is found between overall network density and network density in the initial stage. This finding indicates that most communication takes place in the initial stage because the communication in this stage has the largest effect on the overall outcome. What comes as a surprise is that network density in the initial stage is not related with network density in the intermediate stage. Teams that communicate intensively during the initial stage of emergency response do not keep up their level of communication during the intermediate stage of the response. However, network density in the initial stage is related to network density in the final stage. This implies that teams that communicate intensively in the beginning of an emergency response are also likely to communicate much during the final stage, but not in the middle of the response.

The second step of this analysis relates the amount of communication in different stages to emergency management performance. The outcomes of this analysis do not support the relation described in hypothesis five. Much communication – so high network density and weighted network density – during the initial stage of emergency response is not related to high performance. A decrease of the amount of communication between the initial and intermediate stage is not related to team performance either. The outcomes of this analysis are shown in figure 6.14. Further analysis of the data reveals an unexpected relation. Network density in the intermediate stage of emergency response is negatively correlated with team performance. This trend is shown in figure 6.15. It is not the amount of communication in the initial stage, or the decrease of the amount of information exchange after the initial stage, but the absolute amount of communication in the intermediate stage that turns out to be related with team performance. These findings imply that it is not the initial but the intermediate stage of emergency response that is crucial for the success of on-scene command teams.

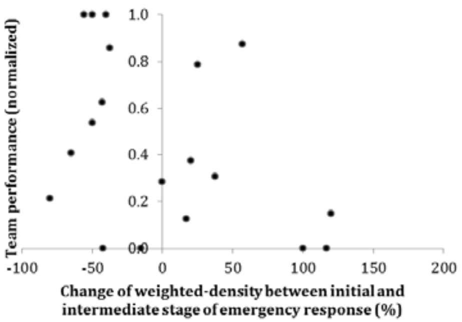


Figure 6.14 - Change in communication density between initial and intermediate stage

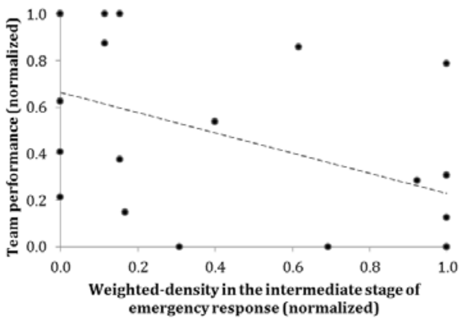


Figure 6.15 - Weighted communication density and team performance in the intermediate stage

In search for additional insights, network density and weighted network density in different stages are also correlated with performance scores at the task, actor, and multidisciplinary subgroup level. This results in two significant outcomes. First, network density in de intermediate stage is negatively associated with performance of the evacuation task, the task that is performed by a subgroup consisting of the police, medical emergency services, and the municipality. More communication within a team during the intermediate stage of emergency response correlates significantly and negatively with the performance of this multidisciplinary subgroup (-0.596**). Second, a significant and negative correlation is found between the amount of communication in the intermediate stage of emergency response and the performance of the medical emergency services and the municipality. This is in line with the outcomes of the multidisciplinary subgroup concerned with evacuation, because both actors are part of this subgroup. Table 6.6 shows the outcomes of the analysis for the evacuation task and the performance of the medical emergency services and the municipality. Chapter five explains how team performance is strongly affected by the performance of the evacuation subgroup. Together, these findings imply that the intermediate stage of emergency response is crucial for the effectiveness of on-scene command teams.

		Evacuation performance	**Medical emergency services performance**	**Municipality performance**
Team communication density during the intermediate stage of emergency response	Pearson Correlation N	-0.596** 20	-.583** 20	-.668** 20
Team weighted communication density during the intermediate stage of emergency response	Pearson Correlation N	-.454* 20	-.434 20	-.505* 20

* = P ≤ 0.05

** = P ≤ 0.01

Table 6.6 - Communication density and evacuation performance

Interim conclusion

Our analysis of communication networks reveals that actors spend comparatively little time on communications and most of their time on the execution of emergency response tasks. The hypothesis that guided our first analysis was that more communication in a team leads to better collective sensemaking and subsequently to higher team performance. Our analysis exposes that teams that communicate more do not perform better than teams that communicate less. Our alternative hypothesis, stating that variation in the amount of communication between actors in a team results in higher team performance, is neither supported by our findings. However, the outcomes suggest that the relation between the amount of communication and performance is influenced by characteristics of an emergency scenario.

The differentiated analysis of communication networks over time provides surprising outcomes. First, teams that communicate intensively during the initial stage of emergency response do not keep up this high level of communications during later stages of the response. In fact, the amount of communication during the initial and intermediate stages of response is unrelated. The hypothesis that much communication during the initial stage of emergency response is related to high performance is not supported. However, the analysis does reveal that the amount of communication during the intermediate stage of the response is negatively related to team performance. The findings indicate that the intermediate stage of emergency response is crucial for understanding operational emergency management performance.

6.5 Conclusion

This chapter addressed the question to what extent and in what manner emergency response actors communicate during emergency response, and how this affects emergency management performance. The analysis provides several insights in the relation between communications and performance and also raises questions on how emergency management performance comes about. The main insights are presented first, followed by the questions that are taken along to the next chapter.

Our first main insights is that the *total amount* of communication between emergency response actors during an emergency response is no indicator of performance. The analysis of the density of communication networks reveals that emergency response actors in the field spend relatively little time on communications and most of their time on organizing and carrying out their tasks. The amount of communication that *does* take place in the field turns out to be unrelated to emergency management performance. Teams that communicate more over the course of an emergency do not perform better than other teams. The presence of multidisciplinary subgroups that communicate intensively – analyzed through the identification of clusters in the communication networks – is not associated with better performance on multidisciplinary tasks. And actors that are strongly involved in communications with other actors are not found to perform systematically better than actors involved in less communication. These findings indicate that effective information exchange and coordination cannot be analyzed through the quantification and accumulation of communication but require a more refined analytical approach.

The second insight is that being important in the emergency response organization – being involved in more communication than others – is not related to actor performance. This suggests that situational awareness, besides not being a matter of having much information, is not a matter of having more information than others. Coordination of individual tasks and orchestrating multidisciplinary tasks effectively does not require actors to dominate the communications.

Our third main insight is that if there is a 'golden hour' for emergency management performance, it is not at the start but halfway an emergency response The dynamic analysis of positions of emergency response actors in communication networks and the dynamic analysis of structural features of communication networks as a whole expose that the amount of communication in the *intermediate* stage of emergency response forms the most insightful period for emergency management performance. Although emergency response actors communicate most in the initial stage of response, the amount of communication in this stage is not systematically associated with performance. The analysis of multidisciplinary subgroups shows that more communication in the intermediate stage is associated with lower performance on multidisciplinary tasks and the dynamic analysis of communication network density reveals that teams with relatively little communication in the intermediate stage outperform teams with more communication in this stage.

The fourth insight is related to the third and entails that the relation between the amount of communication and performance in specific stages of emergency response is inverse. Less communication is associated with better performance during the ' golden hour' of emergency management performance. There are several findings that help explain this insights. First, the analysis of actor positions shows that intensive communication with non-functional relations has a negative effect on actor performance. This suggests that 'distraction' forms a threat to actor performance. More communication does not result in more information exchange or coordination, but more distraction. The observations with regard to variation in the amount of communication between different actors in a team and team performance indicate that collective sensemaking is not a matter of intensive information exchange. These findings suggest that collective sensemaking and coordination either require little communication or do not take place in the field but rather in on-scene command team meetings.

Our fifth main insight is that actors benefit from occupying a central position in a communication network and receiving information during the intermediate stage of emergency response. Being in a central position – being 'in-between' other actors – is systematically associated with actor performance. This insight seems helpful to understand how emergent coordination takes place. The intermediate stage of emergency response is when many emergency response tasks have to be executed. Whereas intensive communication is ineffective in this stage, effectiveness turns out to be associated with the ability of actors to position themselves in between relevant others. In combination with the negative relations between the presence of subgroups within communication networks, the negative effects for actors of being part of a subgroups, and the fact that longer communications are linked to lower performance, these insights indicate that effective emergent coordination is not a matter of extensive communications with multiple actors but the result of short communications with a selective set of functional relations. The analysis of emergent leadership adds that the central player in the selective and short interactions must be a core actor in the response because leadership by non-core actors is found to be associated with low performance. Effective emergent coordination takes place when core actors are able to obtain a position in between other actors and avoid lengthy, non-functional interactions. We also found that actors that receive information during the intermediate stage of emergency response outperform actors who have to look up others to ask for information. This suggests that high performing actors are able to maintain their situational awareness while performing their tasks because information is brought to them. Actors that have to abandon their tasks in search for information postpone the execution of their tasks and therefore achieve less.

These main insights form the foundation for the qualitative, observational account that is presented in the next chapter. Besides the main insights, several open questions remain after the analysis of communication networks that are taken along in the next chapter as well. First, an explanation is needed for why the status of formal leaders in the final stage of emergency response is related to team performance. Second, the reason why some actors get stuck in long, non-productive conversations or conflicts while others communicate swiftly and effectively are yet to be explored. And third, the effects of emergency scenario characteristics are explored to see why it seems more important for teams in some scenarios to have variation in the extent in which actors were involved in communications than in other scenarios.

Chapter 7
Observations: actions that inhibit or support emergency management performance

7.1 Introduction

The key question in this chapter is what (inter)actions of emergency response actors inhibit or support emergency management performance, and how does this influence infrastructure recovery? We present the outcomes of a video-ethnographic, observational inquiry of information exchange and coordination by emergency response actors in the field and during on-scene command team meetings. This in-depth account is both a continuation of the communication network analysis presented in the previous chapter and a selection of autonomous insights. The observations elaborate on the outcomes of the communication network analysis as they provide further explanation for why communication network characteristics are associated with high or low emergency management performance. The observations form an autonomous account because they provide insights from a parallel approach to the communication network analysis that includes aspects of emergency response that cannot be studied by analyzing communications. The account is derived from the purposive selection and systematic comparison of diverse cases. Comparisons are made between high and low performing teams, actors, and subgroups, between teams and actors that received positive and negative feedback in the post-exercise evaluations. and between teams and actors with dense and sparse communication networks.

A part of the qualitative observations is specifically selected to shed light on outcomes of the communication network analysis. All insights from the communication network analysis are explored but three insights are central to this inquiry. First, why is sparse communication in the intermediate stage of emergency response associated with high emergency management performance? Second, why does involvement in communications – especially halfway an emergency response – hamper the performance of individual emergency response actors? And third, how do characteristics of emergency scenarios influence communications between emergency response actors and emergency management performance? The analysis of communication networks did not provide significant insights in the relation between communications in the *initial* stage of emergency response and emergency management performance. This does not mean that what happens during this stage is irrelevant for understanding emergency management performance. Communication network metrics might simply not be able to expose relevant actions and interactions. In this case, qualitative observations might be better suited to explain performance by studying the contents of communications instead of the amount of communication. The remaining observations are therefore used to provide an independent account of actions of emergency response actors, and interactions between emergency response actors, that influence emergency management performance.

The structure of this chapter is in line with our analytical framework of emergency management performance presented in chapter two. Two dimensions are used to accommodate and structure the variety of actions and interactions that take place between actors during emergency response. First, a distinction is made between emergency response during team meetings and emergency response in the field. Second, a distinction is made between actions and interactions related to situational awareness and collective sensemaking and actions and interactions that relate to emergent coordination and emergency decision-making. The two dimensions create four groups of observations, as shown in table 7.1.

	On-scene command team meetings	**Emergency response in the field**
Situational awareness and collective sensemaking	Section 7.2 – How information exchange of emergency response actors during team meetings contributes to situational awareness, collective sensemaking, and emergency management performance.	Section 7.3 – How information exchange between emergency response actors in the field contributes to situational awareness, collective sensemaking, and emergency management performance.
Emergent coordination and emergency decision-making	Section 7.4 – How coordination and emergency decision-making during team meetings contribute to emergency management performance.	Section 7.5 – How emergent coordination and emergency decision-making in the field contribute to emergency management performance.

Table 7.1 – The observational structure in the video-ethnography and outline of this study

Section 7.2 describes information exchange, situational awareness and collective sensemaking during team meetings. Section 7.3 presents actions and interaction that contribute to situational awareness and collective sensemaking in the field. Actions and interactions that relate to (emergent) coordination during team meetings and in the field are addressed in sections 7.4 and 7.5. The sections with outcomes are followed by a discussion of the insights in section 7.6 and a conclusion in section 7.7.

7.2 Situational awareness and collective sensemaking during on-scene command team meetings

Information exchange is a key objective of on-scene command team meetings. The exchange of information is necessary for situational assessment and fuels the shared situational awareness of teams as a whole. Information exchange is necessary for actors to get on the same page and to avoid misunderstandings. As explained in chapter two, information exchange in team meetings has three qualities that set it apart from information exchange in the field. First, exchanging information in meetings makes that information is shared with the entire team instead of a few actors because all emergency response actors are present. Second, information is shared with all actors at once during team meetings, and not conveyed from actor to actor. This makes central information exchange quicker and more efficient than exchange in the field. And third, because of its efficiency and the direct involvement of all actors, information exchange in meetings leaves less room for communication errors and noise than information exchange in the field. Because of these characteristics, central information exchange seems more efficient and effective than information exchange in the field. Information exchange in team meetings is also a challenge. There is generally an abundance of information to share during meetings so actors need to decide what information to share and what not. Sharing irrelevant or indistinct information impedes the situational assessment and consumes time of all members of a team. Information about emergency situations is also notoriously uncertain. This can result in incomplete or contradictory information being presented during meetings, and team having to make clear what information is correct or to cope with ambiguity. In short, information exchange in team meetings is both efficient and effective as well as a challenge for on-scene command teams.

The analysis of communication networks shows that the overall *amount* of communication that goes on between emergency response actors in the field does not provide insight in emergency management performance. The analysis also shows that having much information, or more information than other actors, does not help actors to outperform their peers. These findings suggest that the development of situational awareness and collective sensemaking requires little field communication or does not take place in the field but in on-scene command team meetings. To explore this suggestion, the exchange of information during on-scene command team meetings is studied in-depth to see how it influences situational awareness of individual actors and collective sensemaking of the actors combined.

Studying information exchange in on-scene command team meetings results in two main areas of interest. Most attention is attracted by the process of developing shared understanding of the emergency situation and how the contributions of different actors combine into a coherent picture (or not). This process turns out to be dominated by interactions between actors trying to push their individual concerns and team leaders trying to maintain or restore the structure of team meetings. The second process that draws attention is the reporting of actors to the information manager prior to meetings. This reporting enables actors to put their concerns at the (top of) the response agenda and seems to improve actor performance.

Pushing individual concerns: disrupting team meetings

A main purpose of the meetings of on-scene command teams is that they allow emergency response actors to share and compare their views on an emergency situation. This sharing and comparing is relevant as information is dispersed and uncertain in the immediate aftermath of emergencies. On-scene command teams generally start meetings by creating a shared understanding of the emergency situation, i.e. establishing an accurate and shared view. As explained in chapter two, the development of shared understanding is the start of a three-stage process that consists of creating shared understanding, situational assessment, and emergency decision-making. This three-stage process forms the core structure of on-scene command team meetings.

The information manager plays an important part in creating shared understanding of the emergency situation. The information manager was introduced as an explicit role in on-scene command teams just before this research was conducted. Some of the first teams observed experienced difficulties in accommodating this new role as they tended to use the information manager only to make notes on the meetings. As commented by an information manager of one of the first teams observed *"I'm not a secretary taking notes and drafting a report. I collect information and should be allowed to present the situation when the meeting starts. The team leader needs to provide room for this. I cannot just jump in when the team does not give me the opportunity to do so"*. After some confusion in the first exercises, the role of the information manager became more clear and accepted.

When the information manager fulfills his intended role, the creation of shared understanding of the emergency situation follows a fixed pattern. When meetings start, the team leader asks the information manager to describe the emergency situation as it is known at that moment. The information manager provides his account of the situation, based on information from the emergency dispatch center and information that has been provided by other emergency services prior to the meeting. Once the information manager has described the situation, the team leader asks all actors one by one to add missing information or correct and specify information when necessary. The meetings will ideally only proceed to the next stage – the situational assessment – when the whole team agrees on the presented view of the emergency situation.

The process of creating shared understanding of the emergency situation draws attention during the pairwise comparison of high and low performing teams and actors. In high performing on-scene command teams, it is found that the process of creating shared understanding is often done without interruption and separate from situational assessment and emergency decision-making. In contrast, the creation of shared understanding is found to be disrupted in teams that perform less well. The quality of the process of creating shared understanding is also frequently addressed in the post-exercise evaluations. As expressed by an actor that was part of high performing team five of the Urban hazardous materials scenario: *"what I particularly liked was how the meetings were structured. The team leader used the information manager to describe the situation and let us comment on it. He was very* *strong in getting the picture clear before making any decisions. I liked that because we oversaw the situation before rushing to the response"*. Disruptions of the process of developing shared understanding resulted in criticism on the structure of the meetings during the exercise evaluations.

Disruptions of the process of creating shared understanding take on various forms. Two forms stand out. One is referred to as *early prioritizing* and the other is labelled as *premature assessment or decision-making*. Early prioritizing is observed in several team meetings of poor performing on-scene command teams. In these cases, one or a few actors claim right at the start of the meeting that the priority of the response must be with specific immediate actions, and that the comprehensive process of creating shared understanding, situational assessment, and decision-making must be postponed. The claim that the comprehensive assessment should be postponed is not always stated explicitly but often made implicitly by emphasizing that the prioritized actions must be performed immediately and that further actions make no sense before the prioritized actions are executed. An example of an actor that interrupts the process of creating shared understanding by asking to shift priorities is provided by the fire services of team six that took part in the Westerschelde Tunnel hazardous materials scenario. The first meeting of the on-scene command team has just started, and the tunnel guard is providing additional information to the situation described by the information manager, when the fire services officer interrupts him:

> *"You [tunnel guard] are right; we found a tank truck and a number of passenger cars involved in the accident. The tank truck contains a chemical substance that is thus far unknown. Until we know what is in the truck, you all have to stay out of the accident tunnel. The stuff might be toxic. We have to figure this out before we start the emergency response"*
>
> Medical emergency service officer: *"So no one can enter the tunnel? That's a problem. We have to go in and see whether there are victims and see what their injuries are"*
>
> Fire service officer: *"No, you cannot go in. Not until we know it's safe."*
>
> Medical emergency services officer: *"So can you let me know how many victims are involved? I have to make preparations and ask for transport"* .
>
> Fire services officer: *"Maybe, but I'm focusing on the hazardous materials first. That's our main priority and I will help you as soon as I can"*.

The team continues by discussing whether it is indeed necessary to stay out of the accident tunnel. The discussion ends with the decision to stay out of the accident tunnel and to have the fire services assess the situation with support of video-footage from the tunnel operator.

The medical emergency services continue to prepare their response on basis of the reports from the fire services and the tunnel operator does not initiate any response tasks yet.

A similar example of early prioritizing and disrupting the process of developing shared understanding is found with the fire services and the advisor on hazardous materials in team two of the Urban hazardous material scenario. The information manager has just finished his description of the emergency situation when the advisor on hazardous materials jumps in:

> *"There are cylinders on top of the ship and we do not know what is in there. It is probably gas, butane or propane or something like that. Because of the fire on the ship they are being heated and might explode"*
>
> Team leader: "*Ok, so we have gas cylinders and the chance of an explosion?*"
>
> Fire services officer: *"Yes, an explosion will be immense. We have to get our people of the ship and evacuate the surrounding buildings"*
>
> Police officer: *"There might still be people on the ship. Do we just leave them there? The fire is not on the deck yet. Don't we have time before the threat of an explosion becomes real?"*
>
> Advisor on hazardous materials: *"Maybe, but I'm not sure. If the deck gets hot we may have little time left. If we have to call for an evacuation, we'll be too late"*

The team goes on discussing the chance of an explosion and decides to start evacuating the area surrounding the ship but to keep the firemen on the ship. The fire services monitor the temperature of the cylinders. When the temperature would rise, the fire services would again decide whether to leave the ship and start to fight the fire from a distance. In the two examples, specific actors express their concerns and prioritize a certain course of action. These disruptions and suggestions are accepted by the team and adopted in the emergency response.

The response of other teams to similar disruptions points out that acceptance of disruptions and adoption of the concerns of a disrupting actor is not self-evident. In the Westerschelde Tunnel hazardous materials scenario, several teams decide to grant access to the emergency scene for other emergency services than the fire services under the condition that they stay upwind to the tank truck. In the Urban hazardous materials scenario, some teams decide to cool the gas cylinders and proceed with the rescue operations. The evacuation is also postponed several times and the residents of nearby houses are instructed to stay inside and close their curtains (to prevent glass from flying around if an explosion occurs). In these cases, the concerns of the fire services and the advisor on hazardous materials are not expressed early on in the process of developing shared understanding but later during the situational assessment or as part of emergency decision-making. In other cases, the concerns are expressed but countered by the team leader. These situations are discussed later; the second type of disruptions – *premature assessment or decision-making* – is discussed first.

During observations of poor performing teams it is found that some of these teams engage in situational assessment and decision-making with regard to specific emergency response tasks before the process of developing shared understanding of the situation is completed. What is found as well is that, although these teams performed relatively poorly as a whole, specific individual actors are able to perform better than their peers. In team six in the Westerschelde Tunnel hazardous material scenario, the fire services and police turn out to perform relatively well while the team as a whole performs poorly. In this team, the process of developing shared situational understanding is disrupted by premature situation assessment and emergency decision-making, both in the first and in the second on-scene command team meeting. A similar situation is encountered with the second team in the Port carbon monoxide scenario. In the second meeting of the on-scene command team, the situation regarding the number of children involved in the incident is still unclear. Worried parents have come to the emergency location to find out whether their children are involved in the accident. The information manager starts the team meeting by providing his view of the situation and the police officer is asked to provide his comments:

> *"There are many people coming to the scene right now. They want to know where their children are. I can understand that. We have to await them and bring them somewhere else. To the shelter location?"*
>
> Municipal officer: "*Yes, we have received many worried phone calls and think that many people will get into the car and come to the scene*"
>
> Police officer: *"So we bring them to the shelter location?"*
>
> Municipal officer: "*No, we are registering the children there. If people go there and pick up their children we are lost*"
>
> Police officer: *"Ok, we think of something. But I have to call for additional units. We cannot handle them all by ourselves. We call for reinforcement"*
>
> Team leader: *"The municipality knows what to do? I mean, with the phone calls and the worried parents? Do you have a strategy?"*
>
> Municipal officer: *"Our people in the town hall are working on that but I don't know what their strategy is. Maybe we should ask the mayor to make a statement?"*
>
> Team leader: *"To tell people that we are doing as much as we can and they will get access to their children as soon as possible?"*
>
> Municipal officer: "*Yes, something like that. The team at the town hall will figure that out. I will ask them*"

The example shows how the process of creating shared understanding can swiftly turn into situational assessment and decision-making. The observation that many people are coming to the emergency location is immediately followed by discussing the consequences of the presence of parents and the required reaction from the emergency services. The police proceeds by deciding to call for reinforcements and the municipality decides to ask the mayor to make a statement. Both the police and the municipality perform relatively well in this team (both actors obtain the highest performance score of the actors that take part in the Port carbon monoxide scenario [1/4[12]]). The teams as whole perform averagely.

Disruptions of the process of developing shared understanding of the emergency situation have two types of effects on emergency management performance. The performance of teams as a whole declines when the process is disrupted. The performance of individual actors improves in specific cases. Interruptions provide individual actors with an opportunity to make their concerns dominate the process. These effects are not irreversible because the dominance of a concern cam be nullified in the situational assessment or decision-making stage. However, as the examples make clear, the disruptions influence the priorities and actions of the teams, at least for a while. What enforces these effects is the reluctance or inability of team leaders to return to the process of creating shared understanding after some time has passed. Returning to the process of creating shared situational understanding seems difficult when the on-scene command team meeting is under way for a while. In various teams in which the process of creating shared understanding is disrupted, the team leader states that he wants to continue with the situational assessment and decision-making after the disruption, instead of returning to the development of situational understanding. This shows the importance of team leaders as facilitators of team meetings. Whether actors succeed in interrupting processes during meetings and whether the effects of disruptions are reversed or not, depends to a large extent on how team leaders structure and facilitate meetings. The focus switches therefore to the moves – the counter play – that team leaders provide in response to disruptions of the process of creating shared understanding.

Countering individual concerns: structuring team meetings

Fuzzy and contradictory information is part of all exercise scenarios. Each actor therefore provides his account of the situation at the start of team meetings and the team combines and compares the different accounts to develop an accurate and shared view on the situation. Team leaders play an important role in structuring this process of creating shared understanding. All team leaders have to do at least some structuring during meetings of the on-scene command teams and structuring is observed by leaders of high and low

[12] Performance is expressed by the score of an actor, multidisciplinary subgroup or on-scene command team relative to the other actors, multidisciplinary subgroups or on-scene command teams that took part in the same exercise scenario. [1/4] indicates that the team obtained the highest performance score of the four teams that took part in the same exercise scenario.

performing teams. The attention for how team leaders structure the process of developing shared understanding does not stem from differences in team performance. Instead, it comes from differences in the satisfaction of actors as expressed in the post-exercise evaluations. In the evaluations, some team leaders were praised for their role while others were criticized for not being able to create a clear account of the situation. Two examples from teams that took part in the Westerschelde Tunnel evacuation scenario illustrate the difference between successful and less successful structuring by team leaders. The leader of team four is complimented with his performance while the actors of team two complain about a lack of clarity. As stated by one of the dissatisfied actors: *"when we discussed who should take the non-wounded victims to the shelter locations, we still didn't know the number of people we were talking about. That doesn't work. You need to know how much work it is to bring them outside the tunnel before you can decide who is capable of doing it"*.

On-scene command teams face a difficult situation in the Westerschelde Tunnel evacuation scenario when the second team meeting was about to start. The basics of the situation are clear. An accident has happened in the tunnel and the collision includes a touringcar with senior citizens, a police van in which two convicted criminals are transported, and a number of other vehicles. The passengers of the touringcar are being guided to the non-accident tunnel and the wounded receive medical treatment. The two fugitive criminals have disappeared and it is unclear whether they continue to pose a threat to the emergency responders. In the meantime, the mayors of the two cities on both sides of the tunnel want to know for how long the tunnel will be closed. This is the situation that is assessed at the start of the second team meeting and there are three main issues that actors are bringing forward. First, the fire services, the medical emergency services and the municipality report on the number of victims that are being rescued and transported to hospitals or the shelter location. The situation is challenging because of the large number of victims, their age, and the variety of degrees in which the victims are wounded. Second, the police and the tunnel operator report on the fugitives and the fact that they have escaped and that it is unclear whether they have left the tunnel or not. And third, the tunnel operator and the municipality introduce the request of the mayors about the prognosis of the duration of the tunnel closure.

As with all on-scene command team meetings, the meetings of the teams in the Westerschelde Tunnel evacuation scenario are structured by the three-stage process of developing shared understanding, situation assessment, and decision-making. In the second team that took part in the exercise (the team whose members expressed dissatisfaction with the quality of the team meetings during the post exercise evaluation), the situation of the victims is introduced first during the situation assessment by the medical emergency services. Shortly after the medical officer has started reporting on the situation, the police officer interrupts him with the message that the two fugitives are still in the tunnel. The police officer justifies the interruption by stating that the fugitives might form a threat to the emergency responders and remaining victims and must therefore receive priority. The team leader accepts the interruption of the police officer and asks what the possible presence of the fugitives implies for the response organization. The police officer states that he has to figure that out yet but that all vehicles that enter or leave the tunnel need police escorts. The fire services officer interrupts the police officer and the following conversation enfolds:

Fire services officer: *"Ok, if you need to escort us that's fine, I will have to inform the units immediately because they are getting in and out of the tunnel all the time"*

Police: *"Yes, inform them and tell them that this is important, the fugitives can be dangerous"*

Fire services officer: *"We are dangerous too"*

Police: *"No seriously, we have to be careful"*

Fire services officer: *"Yes, but we are all together on the site and we're only driving up and down the tunnel. The tunnel guard should be more careful when he makes his round"*

Police: *"I think it is important that everybody is being escorted, just in case"*

Medical emergency services officer: *"Isn't it more important to protect the people that are still in the tunnel? Or to get them out? When they're out, they are safe"*

Police: *"That's true but that takes time. So let's take care of the fugitives first before we bring them to the shelter"*

Municipal officer: *"The mayor just called me to ask how long it will take before the tunnel can be reopened. He's getting lots of calls and complaints from companies in the industrial areas. Maybe we can take the victims out while you [the police] are looking for the fugitives?"*

Police: *"I don't know but it might take a while before we can reopen the tunnel. It's a mess at the accident site"*

Fire services officer: *"The mayor will need to have some patience. But we start cleaning the accident site as soon as the cars are being removed"*

Team leader: *"Ok, so we'll have to take care of the fugitives and get the people out of the tunnel"*

Police: *"Yes, and take care of the fugitives first"*

Medical emergency service officer: *"While you take care of the fugitives, I will already talk to the municipality about getting the non-wounded victims out. Maybe we need your help there as well…"*

…

The conversation shows how judgment and decision-making are being blended in the situation assessment. The fire services and the police both try to judge which tasks must be prioritized and what threat stems from the fugitives. The municipality introduces the importance of reopening the tunnel into the discussion. The team leader tries to force a decision about the priorities before returning to the development of a shared situational understanding. In the end, the team decides that the police will escort emergency service vehicles that leave or enter the tunnel and continues with a discussion on who transports non-wounded victims to the shelter locations. With the process of developing shared understanding of the situation unfinished, the team does not know at that point how many non-wounded victims are involved. With much time spend on prioritizing other tasks, the team leader does not want to restart the development of shared situational understanding and the team decides that the municipality has to transport the non-wounded victims without knowing their numbers. The team leader later clarifies that *"when you are in a real emergency, there are people banging on the door and you want to wrap up the meeting as soon as possible. You have to keep the process going and keep it short"*.

The process of developing shared situational understanding in the fourth team that took part in the same scenario evolves differently. When the team starts the process at the beginning of the second team meeting, the medical emergency services also start by reporting on the wounded and non-wounded victims. This time it is the tunnel guard who interrupts because he wants to know whether the tunnel is safe and he can start to inspect the emergency escape routes. The team leader replies that *"that is a valid point and we'll come to that in a minute. Let's get all the facts on the table and then discuss safety"*. A little later, the police reports on the situation of the fugitives when the municipal officer interrupts and asks what this implies for the duration of the situation. The team leader intervenes again, saying *"we will discuss that right away. But let's first finish collecting information and see where we are right now. If we have a clear picture we will see how long it will take to reopen the tunnel"*. When the meeting proceeds, the team decides to make the evacuation task a joint responsibility of the medical emergency services, police and municipality because there are more than forty non-wounded victims in the tunnel. The team leader ends the meeting by stating that *"Evacuation is our most important concern, with so many people involved we have to do that as soon as possible. [to the police] If there are updates on the fugitives, let us know immediately"*.

The effects of this structuring of the team meeting by the team leader are different for team performance and team satisfaction. Appreciation for structuring is expressed in the post-exercise evaluations and seems to have a positive effect on the *satisfaction* of actors about the quality of team meetings. Obviously, team leaders only need to structure a meeting when the three-stage process is disrupted. This means that structuring has a positive effect on the satisfaction of actors with the team meetings. The effects of structuring by team leaders on team *performance* are more complex. As the examples show, the team leader of team two in the Westerschelde Tunnel hazardous materials scenario does not structure the process of creating situational understanding and the team performs comparatively poorly. The team leader of team four structures the process and the team performs comparatively well. The distribution of performance scores over different emergency response tasks varies between the two teams but without remarkable differences. What is worth mentioning is that team four performs better with regard to evacuation and shelter. These processes are at the core of this scenario. Team two, on the other hand, does better on escorting. This indicates that structuring by team leaders puts focus on major tasks in the emergency scenario. The lack of structuring by the team leader of the second team gives the police the opportunity to put escorting on top of the agenda and let it overshadow the evacuation of victims. The actors involved cannot foresee that the fugitives will not cause serious trouble in the exercise scenario. The question what would happen when the scenario involves an escalation of the situation with the fugitives remains unanswered. In that case, the dominant policemen would have been right while the team leader who structures carefully and prioritized the evacuation of victims over the precautions for the fugitive situation might seem negligent. The examples illustrate how the careful structuring of the three-stage process and the creation of shared understanding places the focus of the emergency response on the main concerns as perceived by the majority of the actors while disruptions place the focus on the concerns of one or a few actors.

The comparative observations of high and low performing teams and actors point out how actions of individual actors, and interactions between individual actors and team leaders influence the shared understanding of the emergency situation. Actors that disrupt the standard, three-stage process of team meetings to push their individual concerns are able to change priorities unless they are countered by team leaders or recalled at later stages of the meetings. The interactions between individual actors and team leaders seem to have a significant effect on the shared understanding of the emergency situation and priorities in the emergency response. These observations are interesting in reference to the outcomes of the analysis of communication networks. The outcomes of the network analysis suggest that collective sensemaking either requires little communication or does not take place in the field but rather in on-scene command team meetings. The prioritizing of emergency response tasks through disruptions of the process of creating shared understanding, and the countermoves of team leaders that structure the assessment and focus the emergency response on the perceived core-tasks, support the idea that collective sensemaking does primarily take place during team meetings and not in the field.

An additional finding of the analysis of disruptions of team meetings and the counterplay of team leaders is that the contents and focus of team meetings change over time. Although the three stage structure of the meetings remains the same, the purpose and importance of stages turns out to shift when the emergency response progresses. The first meeting of an on-scene command team is in general primarily aimed at creating a shared understanding of the emergency situation. The creation of shared understanding tends to consume much time in the first meetings and is mainly oriented at the situation at the emergency location, i.e. the characteristics of the accident. When the emergency response progresses, the emergency situation tends to become increasingly clear and creating shared understanding becomes less focused on the emergency situation and more on the emergency response. The increasing familiarity with the emergency situation in later meetings of on-scene command teams also makes that less time is spend on creating shared understanding and more on performing shared situational assessment and emergency decision-making regarding the emergency response.

Setting the agenda: reporting prior to team meetings

A third aspect of information exchange in on-scene command team meetings that draws attention has nothing to do with the interactions between individual actors pushing their concerns and team leaders providing counterplay but involves actors reporting information about the incident to the information manager prior to meetings. The role of the information manager was introduced to the Dutch Incident Command System just before our research started. A core task of information managers is to provide a situational report at the start of a team meeting. The information manager needs to receive or collect information from different actors to be able to provide an accurate and up-to-date report. It is observed in various teams that actors visit the information manager before a meeting starts to provide their information on the situation and their progress in the emergency response. This reporting in advance of team meetings is observed prior to meetings of high as well as low performing teams but especially in relation to actors that perform comparatively well. Two examples from the Port carbon monoxide scenario illustrate the impact of reporting prior to a team meeting on information processing during team meetings.

Prior to the second meeting of team four in the Port carbon monoxide scenario, the officer of the medical emergency services visits the information manager. He gives the information manager the number of victims that has been rescued and that are taken care of in the victim shelter. He provides the number of victims that has been brought to the shelter location of the municipality as well as number of victims that has been brought to hospitals. The information manager checks the victim counts of the medical emergency services with the total number of missing persons – obtained in the first team meeting – and the number of victims that are still missing. The last number is provided by the police right before the second team meeting starts. When the meeting starts, the information manager provides his account of the victims involved in the emergency. The account is checked and confirmed by the officers present in the meeting and the meeting continues with a discussion of other response tasks.

The information manager of the first team in the Port carbon monoxide scenario does not receive any information in advance of the second team meeting. When the meeting starts, the information manager provides his account of the situation based on the previous team meeting. He asks the officers present to make additions to this account. The officers of the medical emergency services and the police provide their updates and comments. This results in confusion as their victim counts do not correspond with the total victim count established in the first team meeting. The confusion results in a discussion with other officers present in the meeting about the accuracy of the common operational picture. In the end, the situation is ended by the team leader and the fire services officer who conclude that the situation is unclear and requires further inspection at the emergency scene.

The collection and verification of information prior to the meeting of team four results in a clear and accurate account of the victims involved in the emergency. The tasks of victim rescue and medical care are on the agenda and the team is able to continue swiftly with other emergency response tasks. The swift and accurate establishment of the situation of victims contributes to a shorter team meeting in which less time is spend on developing a shared understanding and more time on the coordination of emergency response tasks. The absence of reporting in advance of the meeting of team two results in discussion and confusion about the number of victims involved in the emergency during the meeting. The discussion leads to a longer meeting in which most time is spend on creating a shared understanding of the situation.

Reporting in advance of team meetings is observed in high and low performing teams. Reporting is always done by some and not all emergency response actors in the observed teams. This makes it impossible to determine the effect that reporting of all involved actors would have on team performance. However, the example above shows that reporting has a positive effect on the duration of the meeting and places tasks on the meeting agenda. The absence of reporting results in prolonged discussions and lengthening of meetings.

Reporting seems to make a positive contribution to *actor* performance. Actors that report to the information manager prior to a meeting see their concerns placed on the meeting agenda. Because concerns are also introduced during the meetings, reporting is not a necessary condition for actors to perform well. However, because actors that report in advance of meetings are guaranteed to have their concerns discussed, it is reasonable to assume that reporting has a positive effect on actor performance. To explore the suggestion that reporting prior to team meetings is systematically associated with actor performance, the performance scores of actors are studied in relation to their connection with the information manager. Reporting in advance of meetings is described here as part of information exchange *during* team meetings. However, because the contacts between emergency response actors and the information manager take place *before* a meeting, it is counted as interaction in the communication network analysis. Since little interaction between the information manager and other emergency response actors is observed besides reporting prior to meetings, it makes sense to link reporting prior to team meetings to actor performance through the total amount of communication between emergency response actors and the information manager. A correlation analysis of the amount of communication between emergency response actors and the information manager and actor performance provides a positive and significant outcome[13]. Reporting to the information manager in advance of team meetings turns out as an effective way for actors to place their concerns on the meeting agenda.

Interim conclusion

The in-depth study of information exchange in on-scene command team meetings brings forward how situational understanding is shaped by interactions between individual actors pushing their concerns and team leaders structuring the meetings. These interactions seem to dominate the process of collective sensemaking as actors see their concerns become more or less central to the emergency response, depending on their efforts to push their concerns and the countermoves they encounter from team leaders or other actors. The presence of the information manager provides actors with an opportunity to influence situational understanding by putting their concerns on the table, right from the start of a meeting. Actors that contact the information manager prior to team meetings outperform actors that do not contact the information manager.

7.3 Situational awareness and collective sensemaking in the field

Information exchange between emergency response actors in the field is an important aspect of emergency response because it facilitates a faster response than when teams purely rely on information exchange in team meetings. As discussed in chapter two, information can be shared immediately in the field and is therefore much faster than central information exchange where actors have to wait until the meeting starts before they can inform their colleagues. And also, since information is often only relevant for one or a few actors in an on-scene command team, sharing it with the whole team is often unnecessary. Sharing information in the field, with a few relevant actors only, is often sufficient to enable an effective response. There are downsides to information exchange in the field as well. Because information is only shared between a few actors, its accuracy cannot be verified by other actors. It is therefore possible that actors act upon inaccurate or incomplete information while the right information is available by other emergency response actors. Information exchange in the field can also result in a situation in which information is only available in parts of the team. Information exchange in the field can therefore decrease shared situational awareness at the team-level. Information exchange in the field is necessary for a fast and effective response on the one hand while, on the other hand, it can lead to fragmented situational awareness in the team and possible inefficiencies in the emergency response.

[13] $r = .17$, $P \leq 0.01$

The analysis of communication networks points out that the amount of communication between emergency response actors in the field does not predict actor performance. The outcomes suggest that a more refined approach, including qualitative aspects of the exchange of information between actors, is required to understand how emergency management performance comes about. This section presents the main findings of the in-depth, video-ethnographic inquiry of situational awareness and collective sensemaking in the field and relates these findings to emergency management performance. In line with the theoretical tensions described above, the observations on information exchange in the field provide an overview of actions and interactions between emergency response actors that are both positively and negatively associated with emergency management performance. Two dominant themes emerge throughout the analysis. The first theme concerns the way in which emergency response actors handle an uneven distribution of information. The second theme revolves around the formation of subgroups and the effects of the presence of subgroups on the exchange and sharing of information.

Handling an uneven distribution of information: circling, self-imposed isolation, and holding on to experts

A common feature of emergency situations is that some actors have more information than others. This is due to differences in expertise or differences in access to information about the emergency situation. Differences in expertise are the result of different professional backgrounds. When information of some actors is needed by other actors, the uneven distribution of expert knowledge becomes visible. Besides the unequal distribution of expert knowledge, knowledge about the incident situation is also unequally distributed over the emergency response actors. Actors that arrive at the emergency scene first, or that have exclusive access to the accident site, have more information about the emergency situation than actors that arrive later or have limited access to the accident location. This is the case in all exercise scenarios in this study and information is therefore always distributed unevenly over the emergency response actors.

While studying how emergency response actors cope with the uneven distribution of information, three patterns are encountered. First, it is repeatedly observed that actors without access to first-hand information start to circle around the one or few actors with access to the emergency situation. This behavior is labeled *circling*. Second, in response to *circling*, a tendency to isolate oneself from other emergency response actors is observed on the side of actors with first-hand information of the emergency situation. This behavior is labeled *self-imposed isolation*. And third, a pattern is encountered in relation to the uneven distribution of expert knowledge. Experts are frequently asked by other actors to join them in the execution of emergency response tasks. This practice is labeled as *holding on to experts*. These three ways in which actors respond to the uneven distribution of information are further explored in this section.

Circling around core actors is encountered during the observation of relatively low performing actors in teams with dense communication networks. The low performing actors that draw attention are those that are expected to occupy an important position in the team given the characteristics of the emergency scenario. In case of the Westerschelde Tunnel scenarios, for example, these are the fire services – the actor with exclusive access to the accident tunnel. Besides low performing actors, circling is also found when focusing on teams with dense communication networks. Circling is found in teams with dense overall communication networks as well as teams with dense communications in the intermediate stage of emergency response.

The fire services are the primary target of circling in the Westerschelde Tunnel scenarios. The fire services are the first to access and explore the emergency scene because of the possible danger of hazardous materials and smoke. As long as the fire services are exploring the scene, the other disciplines that arrive at the emergency location need to wait until more information is provided. In many cases, the waiting actors contact the fire services frequently with requests for information or to ask whether and when they will be allowed access to the emergency site. In some cases, officers from the police, medical emergency services, the municipality and the tunnel operator gather around the fire services officer and wait for more information to come. The same pattern is observed with the medical emergency services in the Port carbon monoxide scenario. Although the police are the first actor to arrive at the emergency location in this scenario, it is the medical emergency services that have an overview of the number and status of victims. This information is relevant for the municipality and the police as they have to take care of non-injured victims and to inform the public. The police and municipality frequently contact the medical emergency services and stay with them as long as the number and status of victims are not fully known.

The fact that circling is frequently encountered with low performing actors suggests that it has a negative effect on actor performance. The observations on circling indicate that information exchange in the field can be an ineffective and faltering process. Circling consists of series of frequent information requests with little response. The frequent requests for information result in frustration on both sides as the actors that asks does not receive information while the targeted actors are distracted from their tasks. In the words of one of the fire officers in the Westerschelde Tunnel hazardous materials scenario, *"you asked me before about the people in the tunnel but I don't know. And I will not know when you ask again because I am here, in the safe tunnel. I am going to the accident tunnel now and talk to my commander. I'll get to you when I know more"*. The fact that circling is primarily observed with low performing actors suggests that it is a source of distraction that withholds the targeted actors from performing well. These observations are in line with the outcomes of the communication network analysis that indicate that the amount of communication in the intermediate stage of emergency response is negatively associated with performance for both individual actors and teams. As circling is observed in relation to low performing actors and teams with dense communication, it seems at least a part of an explanation for why actors and teams that communicate more than others perform poorly.

A pattern observed on the other side of the uneven distribution of information is *self-imposed isolation*. This pattern is observed with high performing actors who have a substantial role in an emergency scenario – like the fire services in the Westerschelde Tunnel scenarios and the medical emergency services in the Port carbon monoxide scenario. In several exercises it is observed that key actors claim to be too busy with their own monodisciplinary tasks to take part in any contact with other emergency services. The fire services in the second team in the Westerschelde Tunnel hazardous materials scenario, for example, bring out a report in the first team meeting and resume their work as soon as they can. Although other emergency services frequently request information from the fire services, they do not get a response. When asked about the reasons for not joining in a field meeting or taking part in the organization of any other emergency response processes, the fire services officer responds that "*this is the kind of focus that is sometimes needed to get things done. Other emergency services just have to wait. You bring out a report to the team leader when he arrives and you go back to your men in the field. There is no time to start discussing the situation with other disciplines*". The fire services, in this example, choose deliberately to isolate themselves from the larger response organization and to focus on their monodisciplinary tasks.

The same sort of self-imposed isolation is observed with the medical emergency services in the Westerschelde Tunnel evacuation scenario. In this scenario, the medical emergency services have to perform a triage process for a large number of victims. In two teams, the medical emergency services focus exclusively on this process and the requests of ambulances to transport victims to hospitals. Requests from the municipality and the police about the number of non-injured victims and the need for transport to a shelter location are ignored. During the evaluation of the exercises, one of the medical emergency officers explains that "*when the triage started we saw how many people had been brought from the accident tunnel to our field location. We had to act fast and make sure that heavily injured victims were brought to a hospital. The others could wait. We focused on our own objectives first, and we would help the others out if we have time to do so*". Self-imposed isolation is exclusively observed with actors that perform relatively well. The teams of which they are a part do not perform particularly good or bad. So in contrast to circling, which seems to have a negative impact on both actor and team performance, self-imposed isolation seems to have a positive effect on actor performance alone and does not affect the performance of the team as a whole. The finding that being isolated can improve actor performance is in line with the outcomes of the communication network analysis. Less communication with other actors can be positive for actor performance when actors have to execute a substantial set of monodisciplinary tasks.

The pattern of *holding on the experts* is encountered in observations of high performing actors, most obviously in the scenarios that involve the Westerschelde tunnel. A clear example is derived from team two that took part in the Westerschelde Tunnel hazardous materials exercise. When the exercise starts, the fire services are the first to arrive at the emergency location while the tunnel guard drives to the emergency location in the parallel tunnel. After the first inspection of the accident site, the fire services commander goes to the safe tunnel and informs the fire services officer. The officer asks the tunnel guard to join him into the accident tunnel: *"I need you to come with us in case we need anything. We need access to the reservoirs and we need camera footage from the video surveillance system. Stay with us because we will need you"*. The tunnel guard joins the fire services and stays with them until the first on-scene command team meeting is held. In the meantime, the police and medical emergency services that arrive in the safe tunnel are not allowed to enter the accident tunnel because of the risks from hazardous materials. They want to start up their initial response tasks – traffic management and medical care – but lack information on the emergency. The fire services are occupied with the accident and the tunnel guard is with them all the time. The police have to organize traffic management by themselves, without useful knowledge from the tunnel operator. The medical emergency services want to know how many cars are involved in the accident and where they can setup the emergency aid center. The tunnel guard is unavailable for these questions because he is assisting the fire services. This situation lasts until the fire services call for a field meeting. This meeting is used to quickly address the situation and provide information on the number of victims involved. The meeting also gives the police a chance to briefly address traffic management with the tunnel guard and to contact the tunnel operations center.

Another example of holding on to experts stems from the first team that took part in the same Westerschelde Tunnel hazardous materials scenario. In this team, the police officer joins the tunnel guard and asks him to help arrange traffic management at the tunnel entrances. The tunnel guard joins the police until the first on-scene command team meeting starts. The fire and medical emergency services request information from the tunnel guard several times but do not receive a response. As a result, the fire services postpone the collection of leaking substances at the accident site. During the post-exercise evaluation, the fire services officer complains that: *"I needed you [the tunnel guard] right at the beginning. We have to ask a few questions before we can start taking care of the chemicals in the truck. We couldn't find you and that blocked our efforts"*.

Holding on the experts seems beneficial for the actor that puts a claim on the expert's knowledge. It eases information exchange between two specific actors and it frustrates information exchange with other actors and within the team as a whole. The actors described in the examples above perform well. The fire services in the second team in the Westerschelde Tunnel hazardous materials scenario perform better than their peers and the police in the first scenario performs relatively well, especially on traffic management which reaches the highest performance score of all teams that took part in the same exercise. While holding on to experts seems to be beneficial for individual actors, its impact on team performance is mixed. In case of the fire services of team two, the team performs well (second highest performance score out of six teams) while team one – the team of the police who hold on to the tunnel guard – performs poorly (fourth highest performance score out of six teams). An important difference is that the fire services of team two organize a field meeting in which other emergency response actors are updated on the emergency situation and can contact the tunnel guard. The police officer of team one holds on to the tunnel guard until the first team meeting. He thereby obstructs the fire services in obtaining information that helps them to contain the chemical spill. The effects of holding on to experts on team performance seems be determined by the way in which actors use their 'monopoly'. If expert information is shared at some point, the team can still perform well. If expert knowledge is isolated for a significant period of time, team performance seems likely to decline.

The ways in which emergency response actors handle the uneven distribution of information during emergency response influences the performance of individual actors and the emergency response as a whole. Circling around actors with information by actors in need of information is shown to have a negative effect on the performance of key emergency response actors. On the other hand, self-imposed isolation by key actors turns out to be positive for the performance of key actors themselves but decreases emergency management performance as a whole when information is not shared in alternative ways. Holding on to experts is also found to increase the performance of actors that hold on to experts but decreases the effectiveness of the emergency response as a whole.

Organizing multidisciplinary tasks: sharing information in subgroups

Emergency response disciplines start the exercises individually. At the start of the response, each actor looks up its own spot and exercise staff in the field room to get a briefing on the situation and to discuss the initial response. After the start of the exercises it is often observed that the response actors group together in small subgroups. These groups are used to share and compare information and to discuss the emergency situation. This formation of initial subgroups – that are labelled *pockets of information* – is primarily observed in teams with dense communication networks.

Subgroups are formed for different purposes. In some cases actors contact each other because they share responsibility for an emergency response task. In case of multidisciplinary tasks, actor look each other up to discuss a shared course of action. An example of a multidisciplinary task for which actors group together right from the beginning of an exercise is the evacuation and shelter of victims. The group that deals with these tasks consists of the medical emergency services, the municipality, and the police. These actors frequently contact each other early on or halfway the emergency response when victims require transportation from the emergency location to a shelter location. The actors of the evacuation subgroup share information on the number of injured and non-injured victims, the availability and location of a shelter and means for transport.

Not all observed subgroups form around multidisciplinary processes. Subgroups are also formed to discuss the situation in general or because the representatives of different emergency response disciplines are familiar with each other. The subgroups are labelled *pockets of information* because they are used to share information and – as became clear during the post-exercise evaluations – because information is often *only* shared within these specific subgroups. As stated by a police officer after one of the Urban hazardous material exercises, *"I looked up the municipal officer and the medical emergency services and quickly verified how many people were missing. They didn't know for sure either but by putting our information next to each other we could draft a pretty accurate picture"*. This picture of the situation is then used by the police, municipality, and medical emergency services to arrange a shelter location for wounded and non-wounded victims. The jointly created account is not shared with other disciplines. As remarked by the fire service officer: *"I had no idea of the total number of missing passengers. I asked the captain and he told me how many people had been on board. Since I didn't know how many people had been found, we just kept looking in the ship until we heard that everyone was found in the first team meeting"*. The term pocket of information is coined to describe the situation in which emergency response actors share information within a subgroup but not with a team as a whole.

Because pockets of information are observed in high and low performing teams with dense and sparse communication networks, a search for further differentiation of subgroups is started. This results in a distinction between *functional* and *non-functional* subgroups. Functional subgroups are identified as subgroups that emerge around specific multidisciplinary response tasks. An example of a functional subgroup is the cooperation between the fire services, the tunnel operator and the police with regard to the recovery of infrastructure and salvage operations in the scenarios that involved the Westerschelde Tunnel. Subgroups that emerge for other reasons than a multidisciplinary task are labelled as non-functional. A frequently encountered example of a non-functional subgroup stems from the scenarios that involved the Westerschelde Tunnel. In these scenarios, both the medical emergency services and the municipality rely on information from the fire services about the number of victims before they can call for the right resources in response to the accident. As long as the fire services cannot provide this information, both actors have few tasks to manage. Despite this lack of immediate action, the medical emergency services and municipality frequently look each other up in the field and discuss the situation and potential actions. Another example of a non-functional subgroup is observed with the police and the municipality in the Urban hazardous materials scenario. In the early stages of this scenario, the fire services are busy with the ship and little information is available to other emergency services. On several occasions, the police and municipality meet each other in the field and start to discuss the possibilities of a large-scale evacuation.

With the distinction between functional and non-functional subgroups, a link to team performance is made. The emergence of functional subgroups is observed in teams that show strong performance on multidisciplinary tasks. In the Westerschelde Tunnel evacuation exercise, for example, functional subgroups emerge around the evacuation and shelter tasks. Both teams perform well with regard to these tasks. Because these tasks make up an important part of the emergency response in this scenario, the team performance as a whole is high as well. Observations on non-functional subgroups point out that these groups are primarily formed when actors have little or no tasks to attend to. The information that is exchanged in non-functional subgroups is often hypothetical – discussions of 'what-if' scenarios in anticipation of possible things to come. These non-functional groups are found in teams with high and low performance, both with regard to multidisciplinary processes and the team as a whole. The emergence of non-functional subgroups cannot directly be related to team or subgroup performance but the communication that takes place within non-functional subgroups does at least partially explain the negative relation between communication density and team performance that is found in the analysis of communication networks.

The observations on functional and non-functional subgroups draw attention to the role of team leaders in information exchange in the field. Although not all team leaders take part in the emergency responses in the field (some go to the meeting room immediately and stay there for most of the exercise) many make a round along the different emergency services before they go to the meeting room and prepare the first team meeting. In teams with functional subgroups it is observed that team leaders are sometimes the ones who instigate the formation of the groups. When talking about the situation with different emergency services, several team leaders encourage emergency response actors to contact others when the situation required a multidisciplinary response. As the leader of the third team that took part in the Westerschelde Tunnel evacuation scenario explained to the medical emergency services: *"I think you [the medical emergency service officer] have to go to the municipal officer and talk to him about the transport of the people from the touringcar. You're doing well with the wounded victims but there will probably be a lot of non-wounded victims in your field treatment center. Those people have to get out of the tunnel and you must coordinate that with the municipal officer"*. The medical emergency services officer and the municipal officer go on to cooperate well during this exercise and the team performs well on the evacuation task. In other exercises it is also the team leader that – after obtaining a first view of the emergency situation – instigates contact between emergency response actors that are involved in multidisciplinary processes.

Similar instigations are made by team leaders during central meetings. In these situations, team leaders recognize the need for cooperation between two or more emergency response actors when discussing the emergency response. An example is the leader of team six in the Urban hazardous materials scenario. This leader prompts cooperation in the field during the first team meeting: *"I see two important tasks that are not going well yet. We have to take care of the passengers from the ship. We don't have to discuss it now but you [the municipal officer] have to discuss with the medical emergency services* *how you're going to take care of that after the meeting. The other issue is traffic management. The police and the municipality have to arrange a bilat to figure out what area needs to be secured"*. The *bilats* [bilateral meetings] arranged by the team leader take place after the meeting and the team proceeds to obtain good performance scores for evacuation and shelter as well as traffic management. A number of the functional subgroups observed are prompted by team leaders. With their oversight and attention for the emergency response as a whole, team leaders fulfill an important role in the organization of information exchange and coordination with regard to multidisciplinary processes.

The formation of subgroups of emergency response actors is found to be an influential aspect of emergency response. The presence of functional subgroups is found to be associated with strong performance on multidisciplinary tasks. The presence of non-functional subgroups – groups with no direct purpose in the emergency response – do not directly affect team performance. The presence of non-functional subgroups does increase the amount of communication between actors and combining these findings with the outcomes of the communication network analysis suggests that the presence of non-functional subgroups hampers emergency response effectiveness.

Organizing field meetings: sharing all information at once

The most substantive formation of subgroups, and the most organized form of information exchange in the field, is found in the organization of official field meetings. Many of the observed teams (sixteen of the twenty teams observed) organize a field meeting before the first on-scene command team meeting takes place. The organization of field meetings is observed with high and low performing teams with dense and sparse communication networks. The exchange of information in field meetings is discussed separately from the discussion on subgroups, because the meetings can have a significant effect on the situational awareness of actors and plays an important role in the collective sensemaking of on-scene command teams.

In the early stages of emergency response, before on-scene command teams are formed, emergency response actors organize field meetings. Field meetings are generally organized by the first officer that arrives at the emergency location after several other actors arrive at the emergency site as well. By convention, the first officer that arrives at an emergency takes the lead over the overall response – regardless of his disciplinary background – until the team leader arrives and the first meeting of the on-scene command team is held. The first arriving officer can ask colleagues from other disciplines to join in a field meeting. The purpose of a field meeting is to gather and pool information on the emergency situation and to discuss an initial response. In case of small incidents, field meetings are the only form of organized coordination. When an emergency is large enough to call for a GRIP 1 response (see chapter two), on-scene command team meetings are organized and field meetings become an initial and preliminary platform of information exchange and coordination in advance of team meetings.

The scenarios in this study leave room for the organization of field meetings. In the scenarios that involve the Westerschelde Tunnel and the scenario of the Urban hazardous materials, it is the fire services that arrive at the emergency location first. In the Port carbon monoxide scenario, the initial lead is taken by the police as they are the first discipline that is summoned to the ship by the emergency dispatch center. In the exercises, it is approximately the first half hour of the response that is used by individual disciplines to explore the situation and to organize initial response tasks. The field meetings observed vary in duration, the number of actors that take part in the meetings, and the topics that are dealt with. Some field meetings are short updates on the situation – the fire services tell the other emergency services what is going on – and a check whether everyone present in the meeting can start their initial response tasks. Other field meetings are more extensive and include the discussion of dilemma's and alternative approaches to respond to the emergency. Which actors are present in the field meetings varies as well because actors arrive at the emergency location at different moments. The traditional emergency services are quickly present in general while the municipality and the advisor on hazardous materials typically arrive later. The on-scene command team leader normally arrives shortly after the emergency dispatch center or one of the officers at the emergency location calls for a GRIP 1 response. So different emergency response actors are likely to be present depending on the moment at which a field meeting is organized.

The contents and purpose of field meetings vary as well. In its most modest form observed, the field meeting is basically a matter of various emergency service officers listening along with a conversation that is already taking place. In the third team that took part in the Westerschelde Tunnel hazardous materials scenario, the fire services are the only discipline that is allowed to access the emergency scene in the initial stage of the response. The fire services officer arrives in the safe tunnel and receives an update from the fire services commander who has been at the emergency site. The officers of other disciplines gather immediately in the safe tunnel and turn to the fire services for information. The fire services officer decides to ask the officers to listen to his conversation with the fire service commander, *"Come and listen to the report of the commander. But just listen. We have to be fast now and cannot start any discussions. If necessary we call for a field meeting later"*. In a more extensive form, field meetings are organized by the first arriving officer who asks the other officers to join in a meeting. In the scenarios involving the Westerschelde Tunnel, this mainly happens after the fire service commander has informed the fire services officer about the situation in the accident tunnel. This report is often followed by a quick talk between the officers of the different emergency services in which the fire services officer explain the situation and ask the other emergency services whether they can start their response tasks. In its most extensive form observed, a field meeting almost resembles the setup of a formal on-scene command team meeting. The fourth team that took part in the Westerschelde Tunnel evacuation scenario organizes an extensive field meeting at the start of the response. The fire services officer asks the other officers – including the tunnel guard and the municipal officer once he arrives – to join the meeting and start by describing the situation in the accident tunnel as reported by the fire service commander. He then asks the other officers whether they have additional information about the incident. The tunnel guard adds information obtained with the video-surveillance system and all information is written down on paper by the fire services. The fire services officer proceeds by asking and listing the tasks that every discipline has to perform. Once the tasks are listed, the fire services officer starts to describe the necessary response and links tasks to actors. He also specifies which actors have to coordinate multidisciplinary tasks. The contents of this field meeting are very similar to the contents of on-scene command team meetings. During this field meeting, the leader of the on-scene command and control team arrives at the scene and joins the meeting arranged by the fire services officer. The team leader does not take over the field meeting but sporadically provides comments and listens to what is going on.

Because most teams organize a field meeting, it is not possible to identify a link between the presence of field meetings and team performance. However, observations on high performing teams show that all high performing teams in the Westerschelde Tunnel scenario organize extensive field meetings. The highest performing teams are those in which the fire services first isolate themselves from the other emergency services and subsequently organize a field meeting. The organization of field meetings has an effect on the density of communication networks. As many actors simultaneously communicate with each other during a field meeting, the organization of field meetings increases the density of a team's communication network. However, the analysis of communication network density in the initial stage of emergency response – when field meetings are held – is not associated with team performance. This implies that the relation between the amount of communication in the field, the organization of field meetings, and emergency management performance is influenced by other factors that are not identified in the analysis.

Interim conclusion

Situational awareness in the field is determined by the ability of actors to obtain information. The in-depth study of information exchange in the field reveals that information is unevenly distributed over emergency response actors, both as a result of differences in access to the emergency location and differences in expertise. Situational awareness of actors is found to be dependent upon the ability and willingness of actors that have information – about the emergency situation or expert knowledge – to provide information to actors in need of information. The practices of circling, self-imposed isolation, and holding on to experts are mainly observed when actors encounter an uneven distribution of information. The formation of subgroups is observed as an efficient and effective way to share information between several actors but exclusion of relevant actors from important subgroups results in ineffectiveness and lower performance on multidisciplinary tasks. Also, many of the observed subgroups are non-functional and involve communications between emergency response actors without direct benefits for the response. When team leaders become involved in field response, they tend to instigate functional subgroups and bilateral relations. The organization of field meetings enables the exchange of information and is found to influence collective sensemaking as field meetings enable actors to develop an initial, shared account of the emergency situation. Field meetings are mainly effective when key actors isolate themselves to focus on their monodisciplinary tasks before organizing the meeting. The organization of extensive field meetings seems to benefit team performance despite the fact that the communication density associated with field meetings does not correlate with high emergency management performance.

7.4 Coordination and emergency decision-making during on-scene command team meetings

Planning and coordination are the main reasons why on-scene command teams are formed. Planning and coordination in central meetings is required to develop an integral response to an emergency and to make sure that the different disciplines involved do not work past or against each other. The purpose of central planning and coordination is to develop an efficient and effective emergency response on basis of the most complete possible picture of the situation. However, as explained in chapter two, there are two reasons why central planning and coordination can work against an efficient and effective emergency response. First, it can slow down the response because decisions are not made in the field but are postponed to central meetings. This creates a tradeoff between speed and decision-making in the field on the one hand, and keeping an overview and involving the entire response organization but also a slowing down the response on the other. Second, involving all disciplines in the coordination of specific emergency response tasks is often unnecessary. Many emergency response tasks are more or less independent and can be executed in parallel with each other. Such processes require coordination between two or a few actors alone while coordination during team meetings involves actors that have no relation to the task at hand. In sum, the down side of planning and coordination in team meetings is that it can be slow and involves actors that are irrelevant for the process that needs to be coordinated.

The video-ethnographic account reveals several ways in which team performance is influenced by planning and coordination in team meetings. This section starts by describing how emergency response is delayed by indecisiveness in the face of uncertainty. The section continuous by describing how dominant actors push their concerns and how team leaders are able to maintain or regain control of the meeting agenda. The section closes by describing how actors form coalitions to overrule team leaders and push joint concerns.

Dealing with uncertainty: indecisiveness

The information that is available to emergency services during emergency response is regularly incomplete, uncertain, or inconsistent. Different actors receive different sets of information and the information changes over time. This is especially the case for the number of victims involved in the emergency exercises. The number of victims is often uncertain for a while or changes as new victims are found. When emergency response progresses the medical emergency services obtain gradually more information about the number of victims that are injured. The police collects information on how many injured and non-injured victims are gathered at the emergency location. And the municipality knows how many people have arrived at the shelter location by using a registration team that registers everyone involved in the accident. The total number of victims involved in an emergency can only be determined when different actors combine their information. And even if information is shared, there is often uncertainty about the exact numbers, whether they are accurate and whether all types of victims are included. Similar uncertainty about information is encountered in emergencies that involve hazardous materials. The nature of the materials is initially unclear and it takes the fire services and the advisor on hazardous materials time to retrieve information about the materials.

The presence of uncertain situations and incomplete information resulted in difficulties in several teams. These were typically low performing teams. The difficulties are visible in field meetings as well as in on-scene command team meetings. A situation that is frequently observed is that uncertainty about information leads to indecisiveness on the side of the emergency services. Teams postpone decisions to a next meeting or wait for more information to become available. Observations of this kind were labeled as *indecisiveness*.

How indecisiveness comes about can be illustrated by the difficulties that are experienced by the second team that took part in the Urban hazardous materials scenario. The team is confronted with two major uncertainties. First, the number of victims involved in the emergency is unknown as only a few victims have been rescued from the ship and there is no list of passengers available. This aspect is given priority in a field meeting that is organized soon after the different officers arrive at the emergency scene. The medical emergency services and the municipal officer are summoned by the fire services to count the number of victims and to ask the ship owner for a passenger-list. However, the list is not retrieved before the first on-scene command team meeting is organized and there are still only a few passengers found. These passengers tell the medical emergency services that a large group of passengers has been on board that morning. This information results in a very tense situation in the team meeting. The presence of a large group of victims on the ship will require a quick and large-scale rescue operation but nobody is able to confirm whether the passengers are on board or whether they have left the ship already. Second, the fire services have found gas cylinders on the deck of the ship and try to figure out what sort of gas they contain. The presence of the cylinders implies a threat of a gas explosion. This poses a threat to the first responders, the passengers that are possibly still on the ship, and the buildings in the surrounding of the ship. What is vital is that it is impossible to obtain more certainty with regard to both situations without gathering further information. However, the members of team two keep discussing the situation for several minutes. Their conversation is described below:

Municipal officer: *"Maybe some of the victims have fallen in the canal, have you searched there?"*

Fire services officer: *"We didn't see anyone there but I'm not sure... maybe we need help for the search..."*

Team leader: *"We can ask the rescue services… but it takes long before they are here"*

Municipal officer: *"What if people are found in the water, can we get them out and where do we leave them?"*

Police officer: *"Maybe they* [the missing passengers] *are all somewhere in the city center. We don't know. They might just turn up any moment…"*

Team leader: "*That's true but we cannot count on that. We have to arrange facilities to accommodate them and assume that they are injured or suffering from hypothermia*"

Medical emergency services officer: *"Ok, but I don't know for how many people I have to set things up. Do I have to order ambulances all the way from Rotterdam? And what if there is an explosion on the ship? Where do I set things up? I guess there must be a 500 meter range… but if we do that we have to bring injured passengers all the way over…"*

Fire services officer: *"I don't know whether there will be an explosion or not. We can cool the cylinders… Maybe 150 meters is safe enough…"*

Municipal officer: *"And the city building? That is right across the water…"*

Team leader: "*We will see what to do with that in the next meeting*"

Police officer: *"No, I don't agree with that, if we have to evacuate that building we have to start right now"*

Municipal officer: *"But if we do that we have another problem, what about the policy team? If there were international passengers on board and we call for GRIP 3 or higher we have to arrange a team at the city building"*

Team leader: *"Ok, we forward this to the operational team"*

Information manager: *"But we have to decide on the area to evacuate... is it 100, 200, 300 meters?"*

Fire services officer: *"500 meters is necessary to be sure but that is also inconvenient"*

Medical emergency services officer: *"You mean for my people? Yes but it is also about their safety… What do you think?"*

Fire services officer: *"Well, I guess 300 meters is enough… but maybe we need to change that later on…"*

The response to the same uncertainties is different in team six that took part in the same scenario. When confronted with the uncertainty regarding the passengers and the cylinders on the ship, the team leader states that these two aspects require absolute priority. The meeting is ended and the fire services return to the ship while the municipal officers and the police try to contact the ship owner to retrieve the passenger-list.

Fire services officer: *"I don't know what's in the cylinders but we try to figure that out"*

Team leader: *"Ok, so there is one main point now and that is the threat from the cylinders. How about the passengers on the ship?"*

Fire services officer: *"I am not sure but have not found any more people inside thus far. But we keep on searching…"*

Team leader: *"Ok, so that's our second priority, where are the passengers…"*

Municipal officers: "*We receive many phone calls already. People are worried about the smoke. And the city building is right opposite to the ship. What should we do?"*

Police officer: *"There are also complaints from the industrial area of Ramsburg. What should we tell these people?"*

Team leader: *"Ok… can we tell them something already?"*

Fire services officer: "*I think our priority is with the ship now. We just don't know anything else yet"*

Team leader: "Ok, our priority is with the ship and getting people out"

Police officer: *"And the people on the quay?"*

Fire services officer: "*Take them to the victim shelter in the hotel. They can be in danger where they are right now"*

Municipal officer: *"And the municipal building, what do we do with that?"*

Team leader: *"I forward that to the operational team. For now we focus on the fire at the ship. If the fire services see the threat of an explosion growing we will order an evacuation"*

The remaining passengers are found shortly after the first meeting of the on-scene command and control team ends. The uncertainty regarding the remaining passengers on the ship therefore disappears. The cylinders on the deck of the ship turn out to contain butane, a highly explosive gas. The area surrounding the ship needs to be evacuated and the team leader calls for a second meeting to discuss the impact of the evacuation on the processes of the different disciplines. A difference between the two conversations above is that the team leader of team six focuses the emergency response on two priorities: the threat of an explosion and the search for missing passengers. Other issues – like details of the search, the area to be evacuated, and the possible consequences of evacuation the city building – are set aside as less relevant for the moment. Team two, in contrast, takes time to discuss the consequences of the evacuation and other actions.

The first exchange presented above is part of a longer conversation. Various issues are discussed and the meeting takes significantly longer than the meeting of team six. Team six performs much better, overall, than team two. Passages labeled as *indecisiveness* come back more frequently in low than in high performing teams. Uncertainty and indecisiveness have a delaying, and therefore negative effect on emergency management performance. The passages labeled with indecisiveness are also frequently labeled with *actors pushing concerns*. The ferocity with which individual actors push and arrange their concerns is a theme that comes up frequently during the analysis of information exchange and is discussed now.

Prominence and inconspicuousness

Comparison of observations on high and low performing actors reveals a difference in the way in which actors act during on-scene command team meetings. High performing actors are frequently found to talk more and act more dominantly during meetings. High performing actors talk longer, interrupt others more, and are more aggressive in putting their processes at the center of the meeting. Although this type of attitude is not observed with all high performing actors, a pairwise comparison of high and low performing actors from the same disciplines shows that high performing actors are systematically more dominant in the meetings. The behavior of dominant actors is labeled as *prominence* and its counterpart, the lack of visibility during meetings, as *inconspicuousness*.

The fact that differences in dominance drew attention early on during our comparisons of high and low performing actors is partially the result of the way in which performance is measured. Since not only the completion of tasks, but also addressing a task is part of our performance indicator, actors that explicitly address tasks obtain performance scores while actors that remain silent have to obtain results before booking a performance score. Since discussing a task in a team meeting does not necessarily increase the effective execution of the task, the relation between high performance and dominance may thus be the mere consequence of the way in which performance is assessed. However, further comparisons of high and low performing actors show that dominance in team meetings does also result in higher outcome performance. This shows that dominance during team meetings is not only a matter of being clamorous but also results in the faster completion of tasks.

The difference in dominance between actors is illustrated by observations of two tunnel guards that took part in the Westerschelde Tunnel hazardous materials scenario. The tunnel guard of the sixth team that took part in this scenario is asked to comment on the emergency situation during the first team meeting:

> Team leader: "*We have the following situation: eight cars, a tank truck and a van. At least seven people missing and two persons trapped in a car. The fire services will start to rescue them. Is there anything else?*"
>
> Tunnel guard: *"We could see from the video monitoring system that the tank truck is damaged. It is probably leaking something. We have a drainage system to collect the substance if necessary. The fire services can ask if they need it"*
>
> Fire services officer: *"Ok, I'm not sure if the truck is leaking but if that's the case we will need the reservoirs"*
>
> Tunnel guard: *"They are available. And if you need anything to tow cars from the accident site or so, just let us know. We have salvage equipment available. Also for the truck. We will call for that right away because it takes half an hour for them to get to the tunnel"*
>
> Fire services officer: *"I will keep that in mind. I don't think we can start with any salvage operations within the next three hours but we'll see"*
>
> Tunnel guard: *"It's better to have them available"*
>
> Team leader: *"Ok, call them but keep them out of the tunnel as long as we don't need them"*

After the meeting, the fire services confirm the leakage on the tank truck and ask the tunnel guard to help them to contain the substance in the reservoirs. In the second meeting, the fire services ask the tunnel guard about the salvage truck and to bring in the salvage operator to remove the first cars. This is briefly postponed by the police who want to do their investigations but the salvage operations starts just before the third team meeting.

The attitude of this tunnel guard is compared with that of the tunnel guard of the fourth team that took part in the Westerschelde Tunnel hazardous materials scenario. This actor performs relatively poorly. When asked to comment on the situation in the first meeting, the tunnel guard reacts by stating that *"I have no additions for now. I don't think I can do anything because the fire services have to do their work first. But if you need me, just let me know"*. After the meeting, the fire services start to remove the hazardous material that is leaking from the tank truck and call for a special chemical materials removal unit. It is only in the second team meeting that the tunnel guard brings the presence of the reservoirs to their attention. In a similar way, the salvage equipment is ordered in the third team meeting when the municipality asks when the tunnel can be reopened and the tunnel guard is asked to take care of the salvage operations. The visibility of this tunnel guard in the meetings, and the outcomes of the tasks for which he is responsible, are notably lower than the visibility and performance of his colleague in team six.

Prominence seems to contribute to an actor's success but this is not the case for all prominent actors. A few actors are labeled as being prominent but have average or low performance scores. Observing these actors in team meetings reveals that they are contributing to discussions on tasks other than their own. The police officer in the fifth team in the Urban hazardous materials scenario, for example, is labeled as being prominent in all three meetings of his team but performs relatively poorly. His prominence is mainly based on his contributions to the discussion on the evacuation and registration of passengers, a process for which he is not responsible. Being prominent turns out to be an important condition for actors to bring their tasks under the attention of the team and to get their tasks done. Prominence does not necessarily result in high performance because the contributions need to be related to an actor's own tasks to be converted into results.

Agenda control: rearranging priorities

The influence of team leaders on emergency management outcomes becomes increasingly visible when the observations progress from the performance of teams as a whole to the performance of individual actors. Observations on successful teams suggest that team leaders have a positive impact on the performance of a team. Team leaders are able to mitigate the impact of uncertainty and indecisiveness as described in a previous section. Observations on low performing actors and multidisciplinary subgroups point out that team leaders influence the performance of individual actors and groups. The influence of team leaders is captured in two processes that are labeled *agenda setting* and *decision-making*.

The concept of agenda setting is used to describe situations in which a team decides which tasks or concerns to discuss and which to set aside. The selection of issues to address is a typical aspect of the situational assessment stage of on-scene command team meetings as this is the stage in which teams decide which tasks require priority. The video-observations reveal that team leaders play a significant part in this agenda setting process. The concept of *emergency decision-making* is used to label situations in which teams decide which emergency response tasks to take care of, which tasks to prioritize, in what order to execute the tasks, and which actors must take care of which tasks. As expected, emergency decision-making is primarily observed in the last stage of on-scene command team meetings, the decision-making stage. Team leaders are also found to play an important role in emergency decision-making.

The influence of team leaders on *agenda setting* is captured during observations of low performing actors and low performing multidisciplinary subgroups. Our observations on low performing actors make clear that team leaders are capable of keeping individual concerns and emergency response tasks of the table during team meetings. An example relates to the recovery operations in the Westerschelde Tunnel scenarios. In an attempt to make the team focus on the containment of hazardous materials and evacuation of victims, several team leaders dismiss traffic management and recovery as relevant tasks. The team leader of team three in the Westerschelde Tunnel hazardous materials scenario, for example, dismisses concerns about infrastructure recovery by stating that *"I do not care about the tunnel and traffic right now, we first take care of the situation with the hazardous materials and other things are not important at the moment"*. The tunnel guard objects by saying that the tunnel operator and the mayor of Terneuzen want to restore traffic quickly. The team leader replies "*I will contact the mayor or the leader of the operational team and the crisis coordinator of the tunnel and discuss the situation with them. I will meet them after this meeting, for now it is not important*". The team continues to deal relatively poorly with the recovery task [5/6]. The team as a whole performs significantly better [3/6].

A similar example stems from the second team that took part in the Westerschelde Tunnel hazardous materials scenario. This team performs relatively well [2/6], but its performance score is mainly due to high scores on monodisciplinary tasks of the fire services. The subgroup that is responsible for evacuation performs relatively poorly in this team. The focus of this team on fire fighting and containing hazardous materials can primarily be attributed to the team leader. During the first team meeting, the team leader dismisses recovery operations and victim care as secondary objectives (non-priorities) and states that *"the team's absolute priority should be with the hazardous materials"*. The municipal officer resists and wanted to know – on behalf of the mayor – when the tunnel will be reopened. The team leader dismisses this point by stating that it is not relevant at that moment. The meeting ends with a decision to deal with the hazardous materials first and to organize a second meeting later when the materials have been contained. Victim care and recovery could have been initiated so that preparations could be taken but the team leader postpones these issues to the next meeting. Besides relatively poor performance on evacuation and recovery, the actors in this team express their dissatisfaction with the team meetings during the post-exercise evaluations. As stated by the municipal officer: *"The team leader simply dismissed our point by stating that it was irrelevant. But for us it's not. For us it gets interesting when policy dilemmas are discussed. We have to explain later why we did not think of the tunnel and the impact of the accident"*. The examples show how agenda setting by team leaders can have a negative effect on actor performance as team leaders dismiss tasks from the agenda.

Besides keeping issues of the table, team leaders are able to put tasks and concerns on the agenda. This is observed in various high performing teams and it is also a returning theme in the post-exercise evaluations. Some team leaders recognize that a certain emergency response task is being omitted in the response, and step in by asking the team to take care of it. An illustrative example is found in the comparatively high performing team four of the Urban hazardous materials scenario [3/6]. When the team leader is confronted with a hectic second team meeting he tells the team to take care of traffic management. As he states during the post-exercise evaluation: *"I used my position to impose the issue of traffic* *management and to make sure this process was prioritized"*. The traffic management task is important in this scenario as traffic needs to be rerouted to make sure that ambulances and other response vehicles can reach the emergency location. Traffic management is taken care of after the meeting and the team performs relatively well in this respect. The exercise staff comments during the post-exercise evaluation that *"in order to go fast in the hectic circumstances, you have to finish your situational assessment before going to decision-making, otherwise you will omit important issues"*. Team leaders who put neglected tasks on the team's agenda make a positive contribution to the team's overall performance, which is appreciated by other actors.

The influence of team leaders on *emergency decision-making* is primarily observed in high performing teams. In several high performing teams, team leaders make some quick decisions and thereby focus both the meetings and the emergency response. These observations are in contrast with the processes of uncertainty and indecisiveness that have been addressed before. For example, in high performing team four of the Westerschelde Tunnel evacuation scenario [1/6], the team leader makes various quick decisions about which emergency response tasks to start:

> Team leader: *"Ok, now listen, we have a clear situation and I think there are two issues to deal with. First, we have to make sure that we can safely access the tunnel. The fire service will take care of that first. After that we have to bring the passengers to the shelter location. We can start making preparations for that right away"*
>
> Municipal officer: *"Where should we organize a shelter?"*
>
> Team leader: *"That doesn't really matter. Just arrange something nearby. I think the Dow Chemical's farm is fine"*
>
> Municipal officer: *"Ok, and the traffic and people waiting for the tunnel, what do we do with them?"*
>
> Team leader: *"That doesn't matter for now. We first take care of the smoke. Than we do the evacuation. And then we take care of the stuff in the tunnel and make sure that the tunnel can be used again as quickly as possible"*

The example shows how a team leader can quickly prioritize tasks and focus the response on a few core concerns. The quality of quick decision-making is not undisputed. In some cases, quick decision-making results in complaints in the post-exercise evaluations about the role of the team leader. In high performing team five of the Urban hazardous materials scenario, the municipality wants to involve the railway network operator to manage the effects of the smoke for railway traffic and the ship-owner to find out whether there are foreign passengers on board of the ship. The team leader dismisses these suggestions first by claiming that they are not relevant and second by stating that they are the concern of the operational team. The team leader then continues by focusing the response on firefighting and rescuing victims from the ship. The municipal officer complains during the evaluation that there was no room for his concerns during the meetings. The team leader responds by saying that he *"kept these topics out on purpose and pushed them on to the operational team were they belong. The meeting is not a democratic institution, I am the leader of the meeting and I decide in the end which topics are discussed"*. Quick decision-making by team leaders is associated with high performance in the exercises but results in tensions with other emergency response actors.

The apparent advantage of 'macho-style' decision-making

The observations on emergency decision-making by team leaders were often made in situations in which the team discusses the likelihood of future events. In the Westerschelde Tunnel hazardous materials scenario, for example, the teams are generally concerned with the safety of first responders and the possible effects of the leaking chemical substance. Quick decision from team leaders are often aimed at such concerns like whether to allow emergency responders in the tunnel and what distance to keep from the leaking tank. A similar situation exists in the Urban hazardous materials scenario where teams have to deal with the risk of an explosion. The teams are generally concerned with their safety and team leaders see themselves faced with difficult decisions. Several team leaders make the decision not to evacuate and to continue the response. These quick, risky and macho-style decisions contribute to the high performance of both teams. However, the situations do not escalate and there are no explosions or toxic materials in both scenarios. This is in the advantage of risk takers that are rewarded for making quick decisions and continuing the response. The performance of these teams would be lower when the scenario would involve a materializing threat to the first responders. The positive effects of quick decisions that are observed might therefore largely be due to the characteristics of the scenarios that look worrisome at some point but eventually do not escalate.

The observations on agenda control show how team leaders are able to keep concerns from the agenda or put neglected issues on the agenda. Keeping concerns from being addressed in the meetings is likely to result in dissatisfaction on the side of the actors pushing these concerns. However, keeping non-core tasks from the agenda does improve emergency management performance. Team leaders that take risks are rewarded with higher performance scores but this effect is at least partially the result of the exercise scenarios that include risks that do not materialize.

Forming coalitions to jointly push concerns

Similar to prominent actors that are better able to look after their interests than their more inconspicuous peers, the visibility of multidisciplinary subgroups during team meetings varies in accordance with subgroup performance. In teams with high performance on multidisciplinary tasks, the subgroups of actors responsible for the multidisciplinary tasks turns out to be more noticeable in team meetings. Visible subgroups were labeled as *coalitions* during video observations. Coalitions are groups of actors that share responsibility for a specific multidisciplinary task and jointly promote this task. An example of a likely coalition in the scenarios involving the Westerschelde Tunnel is the combination between the municipality and infrastructure operator who have a joint concern for the recovery of disrupted infrastructures. Actors that form coalitions generally find each other in the field and continue to promote their interests together, both in the field and in on-scene command team meetings.

The presence of coalitions is primarily observed in teams with high performing multidisciplinary subgroups. An example of a strong coalition is derived from the third team that took part in the Westerschelde Tunnel evacuation scenario. This team performs better than other teams that took part in the same scenario. This is partially due to a mistake of the exercise staff that untimely releases certain information (see chapter five). However, the strong performance is also the result of the team's high performance with regard to the recovery process. The tunnel guard and the municipal officer encounter each other in the field after the first team meeting. They discuss the emergency situation and the fact that both the mayor and the tunnel operator are concerned about the effects of the tunnel closing on the surrounding area. The tunnel guard and municipal officer jointly address the recovery issue in the second team meeting. Although the team leader dismisses the issue first, the pressure from both actors results in a discussion of several options to restore – at least parts of – the traffic in the tunnel. None of the discussed alternatives are used before the end of the exercise but the recovery process is explicitly on the team's agenda. In the last team meeting, the recovery of the tunnel is one of the first issues addressed and the team decides to remove the debris as soon as possible and provides an estimate of two hours before the tunnel will be reopened.

Another example stems from the sixth team that took part in the Westerschelde Tunnel hazardous materials scenario. In this team the municipality and tunnel guard find each other in the field as well and press the team and team leader to address recovery during the first team meeting. The team leader dismisses the issue by stating that *"I know that the accident has its effects on the traffic and the surroundings. There are definitely economic consequences. I will call the mayor after the meeting and discuss the situation with him. We will leave the issue for now"*. During the evaluation of the exercise, the team leader explained that he "*preferred to discuss the recovery issue with the mayor directly instead of being confronted with pressure during the team meeting*". The municipal officer does not push any further in the meeting and later explains that *"the recovery of the tunnel was still an important concern but the team leader clearly did not want to discuss it. I wanted to discuss the situation again with the tunnel operator after the meeting and call the mayor to get him involved"*. After the meeting, the municipal officer and tunnel guard contact each other and decide to contact the operational team. The operational team agrees with them that recovery is an important process and forwards this message to the team leader. In this way, recovery becomes a prominent topic in the next team meeting. Although this team does not perform well as a whole [4/6] it performs well with respect to recovery [1/6].

The presence of coalitions in teams that perform well on multidisciplinary tasks suggests that actors that align themselves with other actors with similar concerns are better able to look after their own interests. It also shows that multidisciplinary tasks are better performed when multiple actors join each other to look after the task. The two examples that are chosen to illustrate the influence of coalitions also demonstrate that the forming of coalitions results in tensions with the rest of the team and the team leader. Because coalitions have multiple ways to promote their concerns, their efforts are difficult to counter for team leaders. This is illustrated by the way in which the municipal officer and tunnel guard circumvent the team leader in team six of the Westerschelde Tunnel hazardous materials scenario. However, the opposition of the team leader does delay the coalition's attempts.

It is observed that coalitions are often formed in the field and not during on-scene command teams meetings. The analysis of subgroups in communication networks shows that the amount of communication within subgroups is not related to multidisciplinary task performance. These findings combined indicate that the formation of coalitions – which has a positive effect on performance – cannot be identified with network analysis metrics that identify subgroups but is a matter of quality rather than quantity of communication.

Interim conclusion

Emergency response coordination and emergency decision-making are affected by several processes during on-scene command team meetings. Indecisiveness in the face of uncertainty is found to delay emergency response as a whole. Actors with a dominant attitude during meetings perform better than their more timid peers. Team leaders are able to control the meeting agenda which has a positive effect on team performance but is likely to generate dissatisfaction on the side of individual actors. And actors that create coalitions with regard to specific concerns are more successful than individual actors in pushing their concerns, partially because coalitions of actors are difficult to resist by team leaders.

7.5 Emergent coordination and emergency decision-making in the field

Coordination and decision-making form a necessary part of quick and effective emergency response in the field. First responders need to make decisions and startup response tasks immediately. After the first on-scene command team meeting has been organized, coordination tends to become more centralized. However, coordination and decision-making in the field remain relevant. Field coordination is fast and involves relevant actors only. Coordination and decision-making in the field can also harm the efficiency and effectiveness of emergency response because of confusion among actors about what other actors are doing or because of acting upon incomplete information. The role of emergent coordination and emergency decision-making in the field is intriguing because both processes are expected to make positive as well as negative contributions in to emergency management performance.

Our analysis of emergency response communication networks points out that emergency management performance does not originate from an abundance of communication and that what constitutes effective coordination is likely to be dependent upon characteristics of the emergency situation. The video-ethnographic account of emergent coordination and emergency decision-making in the field builds forth upon these findings in search for explanations of how coordinative actions and interactions of actors in the field lead to emergency management performance.

This section starts by explaining how variation in emergency response priorities is not always the result of explicit decisions and continuous by describing how core actors perform better by isolating themselves from the larger emergency response. The section then turns to field coordination and describes how coordination of core tasks by multidisciplinary subgroups results in inefficiency and ineffectiveness. The section closes by describing how emergent leadership by core and non-core actors influences emergency management performance.

Prioritizing tasks: implicit selection

Our observations pointed out that emergency response actors do not deliberately focus on specific response tasks. While the basic response to an emergency scenario was generally the same in each exercise, the attention for specific tasks varied significantly. Actors start tasks at different moments and prioritized tasks differently. Some actors focus on other tasks than others, often without clear or observable reasons. To accommodate such observations in our analysis, a label called *implicit selection* is created. Implicit selection is used to label situations in which actors start one or several specific emergency response tasks while they could also focus on other tasks. Although the choice for specific emergency response tasks is sometimes explained in a later stage or in the post-exercise evaluations, the selection is referred to as implicit because there are no obvious reasons during the moment of initiating the task for why the actors decide to focus on these specific tasks.

To illustrate implicit selection, the choices of two actors are described that find themselves in a similar situation but act differently. Both situations involve the police officer in the Westerschelde Tunnel evacuation scenario. The situations occur halfway the emergency response when the police is facing several problems. The police are requested by the medical emergency services to provide guidance for ambulances that drive from the emergency location to nearby hospitals. The ambulances need an escort to drive quickly through the dense and chaotic traffic at the tunnel entrances. A similar request for guidance comes from the municipality that arranges buses to transport non-injured victims to hospitals. The problems created by the traffic at the tunnel entrances are a shared problem of the police and the tunnel operator. The tunnel operator manages a detour route for road traffic and communicates with drivers waiting at the tunnel entrances with support of digital, adjustable traffic information signs. Given the large numbers of cars at both tunnel entrances, police assistance is required. In sum, the police has to arrange two core tasks at this point in the scenario – traffic management and escorting – and arranges these with the medical emergency services, the municipality, and the tunnel operator.

The police officer of the first team that took part in the evacuation scenario receives the requests for police escorts from the medical emergency services and the municipality. He informs the medical emergency services and the municipality that he calls for additional units to provide escorts but that he first wants to address the situation at the tunnel entrances. The police officer proceeds by going to the tunnel operator to arrange traffic management. After consulting the tunnel operator, he sends two units to the tunnel entrances so they can assist the tunnel operator if necessary. When the third on-scene command team meeting is organized, several ambulances are stuck in traffic because escorting has yet to become effective. Traffic management is taking place but not fully effective as the two police units at the scene cannot handle all traffic. In line with these outcomes, the police receives relatively poor performance scores for traffic management [3/4] and escorting [4/4]. During the evaluation of the exercise, the police officer explains that he called for resources for guiding ambulances and buses. He left it up to the other disciplines to use these or not. Because the other services did not ask for support again, he assumed it was not urgent. He declares that: *"I just told them* [the officers of the medical emergency services and municipality] *that they should let me know if they needed anything and left it up to them to make use of the our support or not. I cannot judge whether support is needed but I have to make sure it is available"*. Furthermore, the officer emphasizes that traffic management was his first priority. He states that accessibility of the tunnel is key to the entire emergency response and adds that *"escorting of ambulances or buses is not needed if traffic is managed well…"*.

The police officer of team four that took part in the Westerschelde Tunnel evacuation scenario takes up a different approach. The police officer, the medical emergency services officer, and the municipal officer hold a short field meeting right after the first on-scene command team meeting. The police officer asks the other officers whether they need assistance on the road and how many ambulances and buses they are using. Both officers indicate that they can use some support and the police orders several additional units. After ordering support, the police officer contacts the tunnel operator and discusses the situation at the tunnel entrances. The tunnel operator asks for support and the police calls additional help. The police returns to each of the other officers when the support arrives. He allocates units to the medical emergency services and the municipality for guidance to hospitals and the shelter location. The remaining units are send to the tunnel operator to provide support for traffic management. The police officer tells the tunnel operator to inform the units when difficulties are encountered with the traffic that is waiting for the tunnel to reopen. The exercise staff soon calls the traffic management issues solved due to the abundant allocation of police units. Given these achievements in the intermediate stage of the response, the police officer obtains a high performance score for traffic management [1/4] and escorting [2/4]. In the evaluation, the police officer states that *"you search for actors with whom you have ground in common. You try to get an overview of the tasks you have to manage together and agree on who will take the lead. The municipality took care of the evacuation and we supported them. The same with the tunnel operator. You have to arrange a division of tasks to settle on a realistic division. There was good coordination between the different disciplines. Some needed support to get to and from the tunnel and I assigned this task to several units. We arranged it quickly and the others understood that it puts a burden on our resources so they acted fast as well"*. The police officer of team four takes up both traffic management and the escorting and does not assign priorities.

A difference between the officers used as an example is that the first officer focuses on one task while the second officer treats both tasks as equally important. Based on their explanations during the evaluations of the exercises, the officers have a different idea of how to approach the situation. The first officer sets his own priorities and thereby prioritizes one task over the other. The other officer focuses on facilitating the other services and therefore focuses on arranging multiple tasks simultaneously. The police officer of team four uses more resources and performs better than his colleague who focuses on one task alone. The examples show that the effects of implicit selection on actor and team performance can be significant. The differences in focus and priorities are among the factors that determine how teams perform with regard to specific tasks. Implicit selection is not specifically observed in relation to high or low performance. The outcomes of analyzing implicit selection are not related to the analysis of communication networks because implicit selection does not necessarily require much or little communication between actors.

Staying away from coordination: self-imposed isolation (again)

The account of situational awareness and collective sensemaking in the field (section 7.3) explains how information is unevenly distributed during emergency response. Asymmetry in the emergency response is also relevant for coordination. It is not only information that is unevenly distributed over emergency response actors; response tasks are also unequally distributed. Some actors have to execute many tasks while others are only partially involved in the emergency response. Many aspects of coordination in the field are found to be related to how actors deal with an uneven distribution of tasks. The observations on situational awareness point out that some actors isolate themselves from other actors to avoid continuous requests for information. Actors that isolate themselves from others in the initial stage of emergency response turn out to perform relatively well. A similar practice is observed in relation to coordination. Observations on actors involved in little communications during the intermediate stage of emergency response point out that high performing actors frequently isolate themselves from the rest of the response. They do not engage in coordinative actions and do not take up a leading role.

An illustrative example of an actor that chooses isolation instead of a coordinating role is provided by the fire services of the second team that took part in the Westerschelde Tunnel hazardous materials scenario. The fire services are a main actor in this scenario because they are the only actor with access to the emergency location for a significant part of the exercise. Moreover, a large part of the tasks required in response to the emergency calls for the involvement of the fire services. The fire services see themselves confronted with a complex emergency situation. The accident concerns a collision of eight cars (including a tank truck and a van), a significant number of victims that need to be rescued, and two types of unidentified chemical materials that need to be contained. All tasks that require action from the fire services. Soon after the fire services officer of team two arrives at the emergency location, he decides to focus on the situational assessment, the rescue of victims and the management of hazardous materials. He provides his account of the situation in the first on-scene command team meeting and declares that he will be occupied with his own monodisciplinary tasks for at least the next thirty minutes. After the first meeting he looks up his commanders in the field and instructs them to keep on assessing the situation and to start with containing the hazardous materials. He briefly contacts the medical emergency services officer and agrees with him to hand over all victims that are encountered at the emergency site. Having a key role in the response, the fire services officer is also contacted by other disciplines. The police wants to join the fire services to investigate the causes of the accident and the tunnel operator wants to assess the accident situation to gather information for salvage operations. These requests of the police and the tunnel operator are ignored by the fire services officer. As he explains to his commander *"I don't want to discuss any other issues. I'm going in now to see how bad things are and I will provide an update in the next team meeting. Everything else has to wait for later…"*. During the evaluation of the exercise, the police and the tunnel operator express their discontent with the fire services. The police wants to voice the concern of starting up the forensic investigation but encounters a *"very non-cooperative fire officer"*. The tunnel operator, who wants to arrange resources for salvage operations, cannot initiate anything because he is not allowed to access the emergency site and does not get any information from the fire services. The tunnel guard explains during the evaluation that the response *"would have taken much longer because it takes the salvage operator sometimes more than an hour to arrive at an accident scene. The sooner you call these guys, the better"*.

The fire services in this example perform well [1/6]. The team as a whole performs relatively well [2/6]. The fire services' decision to operate in relative isolation and focus on their own monodisciplinary tasks seems to result in a high performance score. These observations are in line with the findings of the communication network analysis that show how less communication in the intermediate phase of emergency response is associated with high performing teams and actors. The observations also fit into the findings of more

advanced network metrics that indicate how being positioned in between the right actors while not being involved in long lasting conversations is associated with high performance.
We already discussed how characteristics of an emergency scenario can make that some actors receive an abundance of information while others do not. This imbalance is also found in the number of tasks that an actor is taking care of at different stages of emergency response. The fire services in the hazardous materials scenarios are responsible for assessing the emergency situation and simultaneously have to take care of the fire, contain hazardous materials, search for victims, rescue victims if necessary and consult the advisor on hazardous materials. Other actors have fewer tasks. This asymmetric distribution of tasks is less strong in the Port carbon monoxide and the Westerschelde Tunnel evacuation scenarios. This explains in part why the observations on self-imposed isolation for coordination mainly stem from the hazardous materials scenario. Since these scenarios make up almost two-thirds of the teams observed, it is plausible to assume that the outcomes of the communication network analysis are tilted towards patterns related to an asymmetric distribution of tasks.

Fitting and unfitting leadership

During the analysis of communication networks it was postulated which actors should take the lead in the emergency response given the characteristics of the different emergency scenarios (see chapter six). The analysis shows that different actors are fit to take the lead depending on the mono- and multidisciplinary tasks that need to be executed. The analysis of communication networks also shows that teams in which the 'fitting' actor is the most central actor perform better than teams in which another actor is most central. The link between emergent leadership and team performance is continued in the video-ethnographic analysis to explore what happens when the right or wrong actors take the lead. The moments at which actors take up a leading role in the field were labeled as *emergent leadership*. These moments were compared for high and low performing teams.

The comparison of emergent leadership in high and low performing teams does not result in a coherent pattern. Although the assumed positive effects of core actors taking the lead are found in some teams, it is also observed that core actors are in charge of the field response in low performing teams. High performing teams in which peripheral actors take up a leading role in the response are found as well. The hypothesis that emergent leadership by the right actors contributes to high team performance is therefore difficult to explain. However, the exploration of emergent leadership and team performance does produce two interesting observations. Both observations have to do with scenarios in which the fire services are the key actor; the Westerschelde Tunnel and the Urban hazardous materials scenarios. It was already observed that actors with a substantial role in the emergency response have a tendency to isolate themselves from other response actors. Actors that isolate themselves are found to perform relatively well. When studying high performing teams it is observed that when key actors isolate themselves, the response splits into two parallel streams with an isolated actor and some companions in one stream and other actors in a second stream. This split of the response is illustrated by two teams that deal with hazardous materials. In the second team that took part in the Westerschelde Tunnel hazardous materials scenario, the fire services start to focus on their own monodisciplinary tasks already before the first on-scene command team meeting is held. The officer tells other actors to wait for the team meeting to get an update on the situation and starts the situation assessment in the accident tunnel. After the first team meeting, the fire services keep focusing on their own tasks while the other emergency response actors gather in the field and discuss their common approach to the evacuation of victims and traffic management. The police officer who is involved in evacuation and traffic management takes the lead in this meeting. In the post-exercise evaluation, the police officer explains that "*it was very much a fire services scenario but he [the fire services officer] was so busy with his tasks that we decided not to wait and to see what we could do. I think we arranged everything quite nicely but it felt strange to decide on things without having the fire services officer involved. He was doing his thing over there, and we were organizing our stuff over here. I'm not quite sure whether that was the right thing to do*". In the end, this team performs relatively well [2/6].

A different situation is observed in the fourth team that took part in the Urban hazardous materials scenario. Instead of isolating himself, the fire services officer of this team takes full control of the response before the first team meeting is held. He asks all officers to join him in a field meeting in which he explains the situation as it is known at that point and determines what every emergency discipline is supposed to do. When the field meeting is finished, the emergency services spread out again and focus on their individual tasks. In the first team meeting, the situational assessment from the field meeting is altered slightly and some emergency services change their focus. The core of the response remains similar to what has been decided during the field meeting. The fire services officer calls for a second short field meeting halfway the response. He asks whether all other officers know what they have to do and if he can be of any help. The meeting is short and when it is finished, the emergency services spread again to focus on their individual tasks. The team goes on to perform comparatively well [3/6]. In the post-exercise evaluation, several actors comment on the authoritarian style of the fire services officer. As explained by the municipal officer: "*I was surprised by the first meeting in the field when the fire services officer started to tell everyone what to do. It annoyed me a bit at first but because the meeting was short it was very useful. We could all start with what we had to do and the fire services themselves could focus on all the things they had to do*". The police officer adds that "*it was quite impressive that the fire services, despite the many things they had to do, made time available to see how the response as a whole was going. It was a bit directive but I could understand why because of the time pressure. I think it was the right thing to do*". These examples illustrate how teams have different ways to deal with pressure on a single actor. Moreover, it shows that coordination is not a matter of abundant communication but can take place within a short timeframe. As shown by the example of the second team in the Westerschelde Tunnel hazardous materials scenario, when the core actor does not coordinate the response, another actor can take up the lead. Both observations show how coordination can take place with relatively little communication and still result in high overall emergency management performance.

Leaving core tasks to individual actors or multidisciplinary subgroups

The organization of operational emergency management is dissected in three levels – individual actors, multidisciplinary subgroups, and on-scene command teams – to analyze emergency response and performance. The level at which response tasks are coordinated caught attention when observing low performing teams. It seems that in some low performing teams, the coordination of core tasks in the emergency response is taken care of by a small group of actors. Tasks that are extensively discussed in on-scene command team meetings in most teams are left to bilateral coordination between two actors in some low performing teams. And tasks that are taken care of by multidisciplinary subgroups in most teams are sometimes performed by a single actor. When such differences were encountered, they were labeled as *deviant level of coordination*.

An example that illustrates the possible effects of coordination at a deviant level of the response organization is found in comparatively poor performing team one in the Urban hazardous materials scenario. The evacuation process does not go well in this team and the municipal officer wants to address this in the second on-scene command team meeting. However, the medical emergency services officer interrupts him, claiming that the issue "*is not of interest for all team members*". The team leader asks whether the two actors can address evacuation bilaterally and the medical emergency services officer agrees. The municipal officer protests, saying that he wants to involve the police as well because they can use some support with the evacuation. However, the team leader dismisses the issue and tells the municipal officer to arrange things with the medical emergency services. The evacuation process does not go well in this team [5/6]. After the meeting, the exercise staff comments that "*the concerns of the municipality about the evacuation were valid. Things were not going well. This is central to the response. You cannot dismiss the issue and leave it to the medical emergency services and the municipality alone*".

Another example that illustrates difficulties in coordination due to deviant levels of coordination is encountered in high performing team four in the Port carbon monoxide scenario. In this scenario, the medical emergency services and municipality need to coordinate victim care and shelter as many victims are evacuated from the ship and the temperatures are low. In most cases, the medical emergency services start to organize a shelter and call for additional tents to accommodate non-injured victims. The municipal officer arrives at the scene later and takes over the task of arranging shelter. In team four, the municipality arrives later as well and starts to arrange a shelter location. However, it lasts until the start of the third on-scene command team meeting before the municipal officer hears from the police that non-injured victims are already being sheltered nearby the accident location by the medical emergency services. For most of the exercise, victims are taken in at two locations without emergency services noticing. The team does not perform particularly poor with regard to shelter but the municipality expresses their discontent during the post-exercise evaluation: *"we should have worked together earlier because I feel like we did a lot of things that were not necessary. We had a location prepared when we heard that the victims were already taken care of. That's a shame. We could have sent our registration team to the medical emergency services right away and focus on registration instead of focusing on the shelter"*. This example shows that coordination at lower levels than what regularly is done can decrease the efficiency of the emergency response. Although it is not sure, the team could have done more – and perform better – when the medical emergency services and municipality would not have been organizing the same emergency response task in parallel.

The observations on different levels of coordination are linked to the outcome of the communication network analysis. When the coordination of main emergency response tasks is delegated or left to multidisciplinary subgroups or individual actors, the amount of communication in the field is likely to increase and performance with regard to the task involved is likely to decrease. Coordination at deviant levels also explains in part why some actors seem to get stuck in long, non-productive conversations. The coordination of tasks in small subgroups requires more synchronizing and mobilization of resources compared to coordination of tasks at the level of on-scene command teams as a whole. This synchronizing and mobilizing is one factor that explains why some actors are involved in more communication while performing lower than others.

Interim conclusion

The video-ethnography of coordination and emergency decision-making in the field produces four main insights. First, observations on high and low performing actors show that variation in performance of emergency response tasks is sometimes difficult to explain because actors prioritize and address different tasks without obvious reasons. Although the selection of tasks is logical most of the time, other cases are found in which a clear rationale for task selection is lacking. Second, self-imposed isolation is found to benefit actors with a significant role in the emergency response. This finding is similar to the outcomes of the analysis of information exchange and situational awareness. Third, analysis of emergent leadership and coordination shows how the field response is split in two parallel streams when core actors isolate themselves. Management of the stream with non-core actors turns out to be effective only when another core actor takes the lead. And fourth, variation is observed in the level of the emergency response organization at which tasks are coordinated. Coordination of tasks at lower levels of the emergency response than expected on basis of characteristics of the emergency situation is associated with ineffectiveness and inefficiency.

7.6 The big picture: different contributions to emergency management performance

Pairwise comparison of purposefully selected cases reveals a variety of actions and interactions between emergency response actors that, directly or indirectly, influence emergency management performance. Table 7.2 provides an overview of these actions and interactions and sets them apart on two dimensions. The first dimension involves whether an action makes a positive or negative contribution to emergency management performance. The second dimension explicates whether the contribution is made at the level of individual emergency response tasks, actors, and multidisciplinary subgroups or at the level of on-scene command teams as a whole. The table shows which actions are beneficial for emergency management performance and which are not, and which actions improve performance of specific emergency management objectives and which actions improve emergency management as a whole. The distinctions help to create oversight of the findings and reveal an interesting class of actions and interactions that benefit individual actors but hamper overall emergency response.

The overview in table 7.2 contains two types of actions and interactions. The first type involves actions with a positive effect on the level of individual tasks and actors as well as the level of on-scene command teams as whole. The second type involves actions that have a positive or negative effect on one level and an opposite effect on another level. Most actions and interactions observed are of the first type and have a similar effect on different levels of emergency management performance. Actions and interactions that make a negative contribution to task, actor or multidisciplinary subgroup performance also make a negative contribution to the performance of on-scene command teams as a whole, which makes sense because overall emergency management performance is composed of performance of individual tasks and actors. Circling of peripheral actors around core actors, inconspicuousness during team meetings, and actors being part of non-functional multidisciplinary subgroups are examples of actions that have a negative effect on performance of individual tasks and actors as well as emergency management performance in general. In contrast, actions and interactions that make a positive contribution to task, actor or multidisciplinary subgroup performance do not necessarily have a positive effect on emergency management performance in general. Disrupting the development of shared understanding of the emergency situation, holding on to experts, forming coalitions, and self-imposed isolation without alternative forms of information exchange improve the performance of individual actors but decrease the effectiveness of the overall emergency response. Reporting prior to meetings, coordinating tasks in functional subgroups, and self-imposed isolation in combination with alternative forms of information exchange, on the other hand, improve both the performance of individual actors and emergency management performance in general. Actions that boost performance at the team level, like field meetings (especially in combination with self-imposed isolation by key actors), and coordination in functional subgroups do also improve the performance of individual actors.

Agenda control by team leaders is the only action that improves emergency management performance but tends to decrease actor performance, not in general, but the performance of actors whose concerns threaten to dominate the emergency response. In sum, most actions and interactions contribute either positively or negatively to emergency management performance both in general and with regard to specific tasks and objectives. A smaller subset of actions benefits individual actors but decreases the effectiveness of emergency response as a whole.

	Positive contributions	**Negative contributions**
Emergency management performance	• Team leaders structuring the situation assessment • Agenda control by team leaders • Field meetings (in combination with self-imposed isolation of key actors) • Team leaders that instigate bilateral relations	• Disruptions of the situation assessment • Holding on to experts • Indecisiveness in case of uncertainty • Unfitting emergent leadership • The presence of non-functional subgroups • Deviant levels of coordination
Task, actor or multidisciplinary subgroup performance	• Reporting to the information manager prior to team meetings • Disrupting the situation assessment • Holding on to experts • Self-imposed isolation by key actors • Forming coalitions • Task coordination in functional multidisciplinary subgroups	• Circling around key actors • Inconspicuousness • Being part of non-functional subgroups

Table 7.2 - Positive and negative contributions to emergency management performance and performance of individual actors and multidisciplinary subgroups

The actions and interactions observed in relation to emergency management performance are clustered around two prevailing themes. The first theme concerns actions and interactions that determine the agenda of team meetings. The acts that influence the agenda primarily take place during team meetings but some originate from the response in the field. The second theme involves actions that relate to the uneven distribution of information and tasks. These acts take place in field where the uneven distribution of information is most apparent.

Processes that determine the agenda of on-scene command team meetings often start in the field. Actors that report to the information manager prior to meetings are certain that their concerns are addressed. And actors that meet each other in the field to discuss or coordinate multidisciplinary tasks tend to look after their concerns together during team meetings. During team meetings, interplay is observed between actions to structure the processes of developing shared understanding of the emergency situation, situation assessment, and emergency decision-making and actions that throw these processes of track. When executed as intended, the meeting structure places focus on core response tasks in an emergency scenario, prioritizing tasks that are deemed important by the on-scene command team as a whole. When the structure is disrupted, the concerns of individual actors or specific subgroups tend to dominate the agenda. This is done by prominent actors that disrupt the process of developing shared understanding of the emergency situation or coalitions that promote their concerns together. Team leaders are often found on the opposite side of prominent actors, trying to keep specific concerns from the team's agenda.

The uneven distribution of information during emergency response is described at the start of section 7.3 that describes information exchange and the development of situational awareness in the field. The uneven distribution of information is a factor that was not anticipated on basis of the literature review or communication network analysis but dominated the video-ethnographic observations. Uneven distribution of information is due to differences in expertise and knowledge of the emergency situation. Many of the actions and interaction observed in on-scene command teams relate to this uneven distribution. Actors that lack information circle around key actors to try to obtain information. And actors that have information isolate themselves or search for ways to inform others as efficiently as possible to avoid harmful distraction. Next to the uneven distribution of information there is an uneven distribution of tasks. Some actors have many responsibilities to look after during an emergency while others have relatively little tasks to attend to. This affects the coordinative efforts in a team. Actors with many tasks at hand can further isolate themselves from others or have to find efficient ways to coordinate the response. The presence of actors with less time-consuming tasks at hand at an emergency location can have a negative effect on emergency management effectiveness through the distraction of core actors or the taking up of leadership roles that do not fit the situation at hand. Many of the observed actions and interactions that contribute to team performance are related to the way in which on-scene command teams handle an uneven distribution of information and tasks.

The video-ethnographic account of emergency management builds forth upon the outcomes of the communication network analysis. Some of the observations provide further explanation for outcomes of the communication network analysis. The negative correlation between the amount of communication during the intermediate stage of emergency response and emergency management performance is elucidated by several actions and interactions of emergency response actors. The circling of peripheral actors around key actors and the presence of non-functional multidisciplinary subgroups explain why the amount of communication in the field can hamper effectiveness. Moreover, actions with a negative effect on emergency management performance during team meetings, like disruptions of the development of shared understanding of emergency situations, result in a need for additional coordination – and hence communication – in the field. The negative association between the amount of communication and performance can therefore be explained by a combination of the effectiveness of team meetings and several forms of non-functional communication in the field.

A similar type of explanation is found for the negative association between actor performance and actor involvement in communications in the field. Many forms of communication – discussions in non-functional groups, circling around key actors, coordinating at a deviant level of coordination – do not contribute to actor performance. Such forms of communication distract actors from executing their tasks. At the same time, these forms of distraction are conveniently measured as their effect becomes larger the longer they take. Effective communication, like coordination in functional subgroups or reporting to the information manager prior to meetings, requires little time. Also, most actions and interactions with a positive effect on actor performance take place during team meetings. This explains why the *amount* of field communication is negatively associated with performance of individual emergency response actors. The observations indicate that situational awareness comes from communicating with specific actors that have expert knowledge or information on the emergency situation, or joining in field meetings where all actors are present, rather than communicating much with many different actors. The observations therefore confirm the suggestion of the communication network analysis that situational awareness is about obtaining information from the right actors without being distracted by others.

Circling of peripheral actors around core actors also explains why there is more variation in the number of actors by which individual actors are being contacted than the number of actors that are being contacted by individual actors. The uneven distribution of information makes that some actors are of interest to many others and can receive many requests for information while few actors require information from a many other actors to perform their tasks.

Other outcomes of the communication network analysis are more difficult to explain. The specific position of actors in between other actors is hard to observe qualitatively. The difference between coordination in functional and non-functional subgroups might provide an explanation. Actors in functional subgroups might in general be more central in the response resulting in a higher betweenness centrality for actors that communicate with them. Actors in non-functional subgroups might be involved in much communication communicating with them does not increase an actor’s betweenness centrality because they are peripheral in the communication networks. This hypothesis is not substantiated because the findings of this study do not provide sufficient evidence to link coordination in functional subgroups to core actors and coordination in non-functional subgroups to peripheral actors. The communication network analysis also showed that the degree centrality of team leaders in the final stages of emergency response is associated with emergency management performance. The qualitative observations do not provide further explanation for how this association comes about.

Finally, the communication network analysis points at the influence of emergency scenarios on the relation between communication network characteristics and emergency management performance. The amount of communication between emergency response actors, and the position of individual emergency response actors in the network, has different effects on emergency management performance, depending on specifics of the emergency situation. The video-ethnographic account reveals how the amount of communication between emergency response actors in the field is affected by the way in which information and emergency response tasks are distributed over different emergency response actors. Actors are likely to communicate more – and with less positive consequences for their performance – when information and tasks are unevenly distributed. Uneven distribution of information and tasks makes that key actors are overcharged while more peripheral actors stand at the side. The negative effects of distractive communications and self-imposed isolation of key actors are therefore more likely to be encountered the more uneven the distribution of information and tasks in an emergency situation is. The moderating effect of emergency scenario specifics on the relation between communication network characteristics and emergency management performance is therefore primarily a matter of the degree to which information and tasks are unevenly distributed.

7.7 Conclusion

This chapter set out to describe what (inter)actions of emergency response actors inhibit or support emergency management performance, and how these (inter)actions influences infrastructure recovery. The video-ethnographic observations reveal a rich variety of actions and interactions between emergency response actors, both in the field and during on-scene command team meetings, that contribute to emergency management performance. Actions with a negative impact on emergency management performance are roughly equal in number to actions that make a positive contribution. Most actions have the same impact on different levels of emergency management performance. Actions that increase the effectiveness of individual emergency response actors also tend to improve the effectiveness of the overall emergency response and vice versa. However, several actions and interactions are found that increase the performance of individual actors – and therefore benefit specific emergency management objectives – while decreasing emergency management performance as a whole. The actions and interactions provide a rich set of explanations for how variation in emergency management performance comes about, why some on-scene command teams perform better than others, and why infrastructures are recovered more quickly on some occasions than others.

The observations are dominated by two themes. The first theme is agenda control. Most actions observed during on-scene command team meetings are related to getting concerns on and off the meeting's agenda. Individual actors use several tactics to push individual concerns while team leaders maneuver in different ways to structure meetings and prevent individual concerns from dominating the response. The second theme is uneven distribution of information and tasks. Because some actors have more information at their disposal than others, many actions and interactions observed in the field relate to getting information from few actors to many. And because core actors have many response tasks to perform, they have to abstain from getting distracted by too many information requests or coordinative actors to perform well.

The in-depth observations explain some outcomes of the communication network analysis. The negative association between the amount of communication and emergency management performance is explained by several forms of non-functional communication in the field and the fact that most actions that boost team performance require relatively little communication. The negative association between actor involvement in communications and actor performance is explained by the intensity of communication that comes with actions that tend to decrease actor performance and the fact that actions that increase actor performance tend to take place during on-scene command team meetings. Other outcomes of the communication network analysis are more difficult to explain with in-depth observations and cannot be related to systematically observed differences between high and low performing actors or teams. Betweenness centrality seems to be a powerful analytical notion that is difficult to observe. The combined observations indicate that the degree in which information and tasks are unevenly distributed influences the effect that communication network characteristics – and the underlying actions and interaction of emergency response actors – have on emergency management performance.

Chapter 8
Conclusions

8.1 Introduction

The increasing complexity of infrastructures makes it more and more difficult to anticipate adverse events and necessitates infrastructure operators and emergency services to increase their resilience, meaning their ability to respond to complex events and manage multiple objectives effectively, including the recovery of disrupted infrastructures. In the context of these trends, we questioned: (i) how emergency response actors coordinate multiple emergency management objectives and procedures, and (ii) how the way they do this determines their emergency management performance. Our investigations reveal a wide and previously undisclosed variety of coordinative actions and interactions between emergency response actors in the field and during on-scene command team meetings. These outcomes show how the combined (inter)actions of emergency response actors determine emergency management performance.

This chapter presents an overview of the empirical findings to show how emergency response actors coordinate multiple emergency management objectives (section 8.2). On basis of these findings, a new conceptual framework and a taxonomy of emergency management processes are presented that help explain how emergency management processes determine emergency management performance (section 8.3). The chapter closes by embedding our findings in the broader field of emergency management and making the case that operational emergency management should be perceived as a multi-actor response arena rather than a system of command and control (section 8.4).

8.2 Coordinating multiple emergency management objectives

Our first research objective is to understand how multiple emergency management objectives are coordinated during operational emergency response. Our empirical investigations provide three sorts of findings:

1. Elaborations of emergency management processes: driving, hampering, and altering emergency management performance.
2. New findings: mind the transitions between field response and central meetings.
3. Advanced insights in temporal aspects of emergency management processes.

Elaborations of emergency management processes: driving, hampering, and altering emergency management performance

Our investigations were based on a taxonomic scheme of four emergency management processes that were hypothesized to enable emergency management performance: 1) situational awareness, 2) emergent coordination, 3) collective sensemaking, and 4) emergency decision-making (see chapter two). The inquiries confirm the relevance of these four processes for understanding emergency management performance. Our research also reveals detailed sub-processes that provide more specific insights in the workings of the four emergency management processes. The sub-processes discovered do not merely *enable* performance; some *enhance* emergency management performance, while others make a *negative* contribution or *adjust* performance in the sense that performance with regard to certain objectives increases while performance with regard to other objectives declines. The four emergency management processes and the sub-processes are discussed together with their effects on emergency management performance.

Situational awareness. Situational awareness, the development and maintenance of an accurate understanding of emergency situations by response actors, is crucial for emergency management performance. Having sufficient and up-to-date information is key to the development of an effective emergency response. Four processes between emergency response actors in the field are found that help to understand how situational awareness is developed and maintained (or not), and how situational awareness contributes to emergency management performance. These processes are: 1) holding on to experts, 2) self-imposed isolation by key actors, 3) circling around key actors, and 4) organizing field meetings.

Developing and maintaining situational awareness is not simply a matter of collecting as much information as one possibly can, but involves the capability of obtaining access to the right sources of information. Obtaining such access is complicated as a result of the uneven distribution of information across emergency response actors. This uneven information distribution is the result of differences in access to the emergency site, differences in expertise, and holding on to experts; the claiming of exclusive contacts with an actor that possesses information or knowledge by a single emergency response actor.

Holding on to an expert increases the situational awareness of a specific actor while it obstructs the chances of others to obtain expert knowledge. The uneven distribution of information in emergency response teams makes that many actors are dependent upon a few key emergency responders for the development of situational awareness. When key actors isolate themselves from others – they focus on their own tasks and ignore information requests from others –, they reduce the chances of others to become situationally aware and to organize an effective response for themselves and the emergency discipline they represent. When non-key actors, in response to the uneven distribution of information and possibly the self-imposed isolation of key actors, start to circle around key actors – i.e. standing close by in expectation of information or frequently requesting information –, they reduce the effectiveness of key actors via their information requests. The organization of field meetings seems to provide an effective way to increase situational awareness within the larger response organization. The organization of field meetings has a particularly positive effect on emergency management performance when key actors isolate themselves before and after the meetings.

Emergent coordination. Emergent coordination of response tasks in the field is necessary to enable a swift response and emergency response tasks are commonly initiated and orchestrated in the field. Five sub-processes were identified in the field that help to understand coordination in emergency response. These processes are: 1) self-imposed isolation by key actors, 2) coordination by non-key actors, 3) coordination in functional and 4) in non-functional multidisciplinary subgroups, and 5) coordination at unsuitable levels of the response organization.

The uneven distribution of tasks between emergency response actors plays a prominent role in how emergent coordination evolves and whether coordinative efforts become successful or not. Actors with many tasks at hand frequently isolate themselves from the larger emergency response to focus on their own tasks alone. Such self-imposed isolation tends to improve the performance of key actors and does not necessarily reduce the effectiveness of the larger emergency response. However, emergency management performance tends to decrease when non-key actors take up a leading coordinative role in the absence of key actors. Emergent coordination in the field is observed to be primarily a matter of gathering actors, deciding upon response priorities, and initiating and orchestrating response tasks. Success in emergent coordination depends upon the composition of the subgroups of actors in which response tasks are being coordinated. The first step in emergent coordination, the gathering of actors, is therefore crucial for successful emergent coordination. Subgroups of actors are observed to be successful when they emerge around a specific multidisciplinary task and only involve the key actors responsible for this task. The formation of such *functional* subgroups contributes positively to emergency management performance, in general and especially with regard to the multidisciplinary task in question. In contrast, subgroups that emerge along *non-functional* characteristics prolong communication between actors with no specific shared tasks and is associated with lower performance, both for the actors involved in the non-functional subgroup and emergency response in general. A last outcome with regard to emergent coordination is that tasks must be coordinated at the 'right' or suitable level of coordination. Key tasks in the response to an emergency must be coordinated by on-scene command teams as a whole, even though not all actors are involved in the task. Key tasks that are delegated to subgroups or individual actors are generally performed poorly.

Collective sensemaking. On-scene command teams spend a substantial part of their meetings on collectively making sense of emergency situations. Our research provides evidence that the way in which the process of sensemaking evolves influences emergency management performance. Four practices were observed that shape the collective sensemaking process: 1) prominence and inconspicuousness of individual emergency response actors, 2) disruptions of the development of shared situational understanding, 3) agenda control by team leaders, and 4) the formation of coalitions.

Systematic observations of team meetings show that the amount of attention paid to different aspects of emergencies varies significantly between teams even though the teams respond to identical emergency situations. What aspects are discussed in a team meeting is primarily the product of the interactions between individual actors that push their concerns and team leaders' assessments of the appropriateness of the amount of attention paid to different concerns. The success of actors to push their concerns varies in accordance with their prominence or inconspicuousness during meetings, i.e. speaking up and actively promoting interests and concerns. The factors that drive prominence or inconspicuousness are beyond the scope of our analysis but the behavior itself is systematically associated with individual performance. The most frequently observed successful way to push individual concerns during team meetings is by disrupting the processes of developing shared situational understanding and situational assessment.

Actors that disrupt these team meeting processes often succeed in getting more attention for their concerns. The pushing of individual concerns on the response agenda adjusts emergency management performance in the sense that it causes teams to focus on specific, sometimes peripheral tasks instead of developing a comprehensive response. Team leaders act as a counterforce against prominent actors. Team leaders try to control the meeting agenda by dismissing concerns brought up by individual actors or by directing the team to follow the usual pattern of creating shared understanding, situational assessment, and decision-making. In later stages of emergency response, actors may form coalitions to jointly push concerns. Team leaders have more difficulty countering the concerns pushed by coalitions than countering the concerns of individual actors.

Emergency decision-making. Formal decision-making is a relatively minor part of operational emergency management. Although emergency situations force on-scene command teams to choose which response tasks to prioritize, these choices are rarely made deliberately through explicit decision-making processes. Choices are most of the time the implicit outcomes of interactions between response actors. Only one aspect related to emergency decision-making is systematically observed: indecisiveness in the face of uncertainty. Teams that are indecisive in the face of uncertainty – engaging in lengthy discussions and postponing choices –perform less well than teams that select a course of action more quickly. This is partially due to the conditions of emergency response in which every second counts and quick decision-making is necessary to limit damage and to save lives. However, the success of quick and resolute decisions seems also due to specific scenario characteristics. All scenarios in this study present risks that never materialize. This systematically favors risk taking over cautiousness. The systematically observed negative effects of indecisiveness are therefore at least partially due to scenario characteristics.

New findings: mind the transitions between field response and central meetings

In accordance with the reference model of Marks, Mathieu, and Zaccaro (2001), our analytical framework indicated that action and transition phases follow each other in chronological order, and that outputs of actions phases are inputs for transition phases and vice versa. The taxonomy of processes described by Marks and her colleagues and our taxonomy of emergency management processes do not specify how the transfer of inputs and outputs between phases takes place. However, the results of our investigations indicate that what happens during the transitions between emergency response in the field and team meetings influences what happens in the subsequent phase and emergency management performance. Two specific practices stand out: 1) instigating bilateral relations by team leaders, and 2) reporting to the information manager prior to meetings.

Instigating bilateral relations. Observations on emergent coordination in the field make clear that coordination with the right combination of actors is crucial for emergency management performance. Team leaders explicitly orchestrate coordination between specific actors at the end of on-scene command team meetings. Team leaders of high performing teams manage to keep the team meetings short and delegate tasks to specific subgroups. Delegation is realized by instigating specific bilateral or multilateral relations. By instigating the coordination during the meetings, team leaders make sure that tasks are coordinated in the field by the right group of actors, without interference of others.

Reporting to information managers. The observations on collective sensemaking show that influence on the topics that are discussed during team meetings is crucial for emergency management performance. Actors that report to the information manager prior to team meetings are guaranteed to have their concerns addressed and perform better than actors that join meeting without reporting. Reporting is found to function as a form of agenda setting for the team meeting. The observations show that steering the meeting agenda starts in the field, prior to the meeting itself. The findings on transition processes show that the setting of emergency response is partially created in prior phases. In other words, the approach taken by individual actors influences the outcome and their level of involvement in the emergency. Team leaders create the setting for field response by instigating bilateral and multilateral coordination and actors influence the setting of team meetings by contacting the information manager before a meeting starts.

Advanced insights in temporal aspects of emergency management processes

Our analytical framework did not accommodate any differences in the nature of emergency management processes in the field or during team meetings when emergency response progresses. The framework therefore assumed that the processes that determine emergency management performance remain similar over time. We found that the nature of emergency response, and the relevance of specific emergency management processes, does change over time. The communication patterns and video observations show that situational awareness, collective sensemaking and emergent coordination are especially influential and relevant at specific stages during emergency response.

By differentiating between an initial, intermediate and final stage, a longitudinal approach was adopted that enabled us to study the dynamics of emergency response and to see what processes matter at what point. This distinction proves useful because the amount of communication in the intermediate stage of emergency response is negatively associated with performance. Subsequent observations showed that this is the combined result of coordination in non-functional subgroups and coordination by non-key actors. Specific characteristics of the position of actors within communication networks during the intermediate stage are positively associated with actor performance. This is explained by coordination in functional subgroups, especially by key actors. Although communication network characteristics are not related to emergency management performance in the initial stage of emergency response, the qualitative observations revealed that the development of situational awareness is primarily an issue at the start of emergency response. How actors cope with the uneven distribution of information determines whether many actors become situationally aware or whether crucial information stays with a few key actors. The same is true for collective sensemaking, because pushing concerns to the center of attention has a larger effect on performance in early stages of emergency response than later stages. The distinction of a final stage of emergency response did not result in additional insights.

The temporal insights make it possible to identify particular stages of emergency response at which specific emergency management processes have their most profound impact on emergency management performance. Situational awareness and collective sensemaking are most relevant at the early stages of emergency response while emergent coordination becomes more influential when emergency response progresses. These findings form part of a first answer to the call to better understand temporal aspects of emergency management (Helsloot, 2008) and imply that coordination and performance require different qualities during different phases of emergency management, from mitigation to preparation, response, restoration and recovery (see also Pettersen & Schulman, 2016).

8.3 Towards better understanding of emergency management performance

Our overview of emergency management processes shows how on-scene command teams coordinate multiple emergency management objectives. This section deals with our second research question; how does the way in which emergency response actors coordinate emergency management processes determine emergency management performance. Our findings are used to draw inferences in relation to the analytical framework of emergency management performance and the taxonomy of emergency management processes. The inferences are used to present a revised conceptual framework and enriched taxonomy that are more suitable for understanding and explaining emergency management performance. The theoretical implications of the revised conceptual framework and enriched taxonomy are discussed.

A more adequate framework

The combined research findings enable us to present a revised conceptual framework for operational emergency management performance. The framework is shown in figure 8.

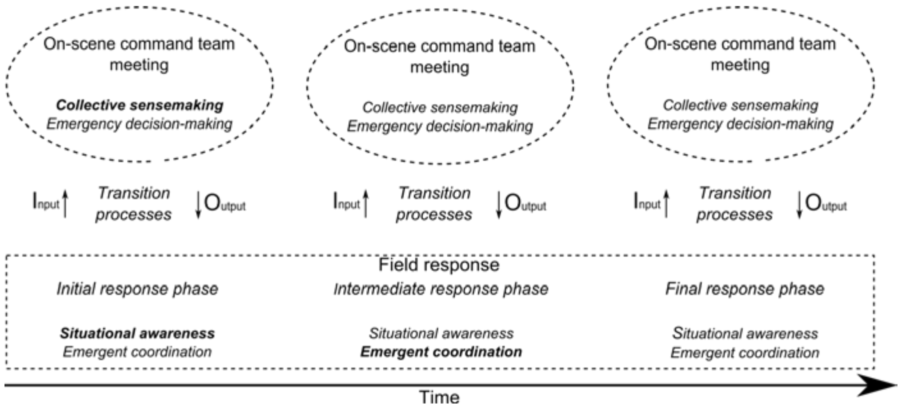


Figure 8 – Revised conceptual framework for emergency management performance

The revised conceptual framework differs from the analytical framework used in this study (see chapter two) in that it depicts emergency response in the field taking place continuously and thus *parallel* alongside on-scene command team meetings, instead of *alternating* emergency response in the field and on-scene command team meetings. The framework also differs in that it is temporally differentiated in three stages (initial response, intermediate response phase, and final response) to indicate at what moment in the emergency response the four emergency management processes (situational awareness, collective sensemaking, emergent coordination, and emergency decision-making) are most influential for emergency management performance. The conceptual framework also includes the processes that are associated with the transitions between emergency response in the field and on-scene command team meetings.

Our analytical framework reduced the framework of Marks, Mathieu, and Zaccaro (2001) to a single beat of alternating phases to suit the conditions and practice of operational emergency management. The distinction between action and transition phases proved adequate for understanding operational emergency management as different emergency management processes are associated with emergency response in the field and during on-scene command team meetings. The sequential approach of alternating phases turned out to be less suitable for understanding operational emergency management. Our findings indicate that emergency response is not characterized by a sequence of alternating phases but by a continuous line of action and a parallel sequence of on-scene command team meetings. While emergency response actors reflect on the emergency situation during the meetings, the situation keeps evolving and the response keeps progressing. Action and transition phases in operational emergency management should therefore be less perceived as sequential and more as parallel. This situation is partially unique for crisis conditions that necessitate for immediate and continuous action but might be found in other situations involving time pressure or uninterruptable processes as well. To accommodate these findings, the revised conceptual framework of operational emergency management performance presents emergency response in the field as a continuous action phase while on-scene command team meetings are taking place in parallel.

Our analytical framework included four emergency management processes. Our research provides several emergency management processes that do not fit the framework and point towards an additional, third group of relevant emergency management processes. Because the newly found processes are associated with the transitions between emergency response in the field an on-scene command team meetings, a third category of *transition* processes is introduced in the revised conceptual framework. These transition processes determine how outputs from emergency response in the field influences on-scene command teams and vice versa. The introduction of transition processes poses a semantic challenge because the original framework of Marks, Mathieu, and Zaccaro (2001) refers to meetings as transition phases. To solve this, we refer to meetings as reflection phases and place transition phases in between action phases (field response) and reflection phases (on-scene command team meetings).

The finding that the influence of different emergency management processes varies during different stages of emergency response implies that the explanatory power of an analytical framework increases when the framework is temporally differentiated. These findings are in line with the call of Marks, Mathieu, and Zaccaro (2001) to further develop their framework on the temporal dimension. Our findings provide directions for the level of temporal differentiation and identify which emergency management processes are influential during what stage of emergency response. The distinction between an initial, intermediate, and final stage proves useful for the analysis of operational emergency management. Processes related to situational awareness and collective sensemaking dominate the initial stage while emergent coordination proves to be most influential during the intermediate stage of emergency response. The revised conceptual framework of operational emergency management performance includes this basic form of temporal differentiation and explicates which emergency management processes are most important at what stage of emergency response.

A richer taxonomy

The detailed sub-processes found in relation to situational awareness, emergent coordination, collective sensemaking and emergency decision-making, and the discovery of transition processes, make it possible to develop an enriched taxonomy of emergency management processes. The sub-processes do not merely *enable* performance but have positive, negative or altering effects, which makes that emergency management performance of on-scene command teams as a whole is the outcome of the combined processes that take place during the response of this team to an emergency. Table 8 presents our enriched taxonomy of emergency management processes and indicates for each process whether it has a positive, negative or adjusting effect on emergency management performance.

Situational awareness, the development and maintenance of an operational picture and adequate understanding of the emergency situation, is generally conceived as a necessary condition for emergency management performance and break-downs of situational awareness are assumed to result in reduced performance or failures (Sonnenwald & Pierce, 2000). Our findings show that developing situational awareness is a failure-prone process consisting of several more specific processes in the context of an uneven distribution of information over emergency response actors. Most processes observed – self-imposed isolation of key actors, circling around key actors, and holding on to experts – hamper the development of situational awareness. The organization of field meetings is the only process that increases situational awareness. The organization of field meetings has a positive effect on emergency management performance but to varying degrees. Most teams observed organized some form of field meeting and some were more effective than others. This calls for further research to determine what distinguishes successful from less successful field meetings. The development of situational awareness is not related to the amount of communication and information that is exchanged within a team. Situational awareness and information exchange are difficult to quantify and useful metrics to identify successful information exchange in communication networks are yet to be developed.

Taxonomy of emergency management processes

<u>Emergency management processes in the field:</u>

Situational awareness

+ Organizing field meetings (++ in combination with self-imposed isolation of key actors)
- Holding on to experts
- Self-imposed isolation from information exchange by key actors
- Circling around key actors

Emergent coordination

+ Coordination in functional subgroups
- Coordination by non-key actors
- Coordination in non-functional subgroups
- Delegating key tasks to subgroups or individual actors
~ Self-imposed isolation from coordination by key actors

<u>Transition processes:</u>

+ Instigating bilateral and multilateral coordination
~ Reporting to the information manager

<u>Emergency management processes in team meetings:</u>

Collective sensemaking

+ Agenda control by team leaders
~ Actor prominence
~ Actor inconspicuousness
~ Disrupting the development of shared understanding of the emergency situation
~ Forming coalitions

Emergency decision-making

- Indecisiveness in response to uncertainty

+ = enhancing performance, - = reducing performance, ~ = adjusting performance

Table 8 - Enriched taxonomy of emergency management processes

The findings of more specific sub-processes of situational awareness are relevant in the context of recent research on network centric operations; information technology supported efforts to make information available to all (Von Lubitz, Beakley, and Patricelli, 2008; Wolbers & Boersma, 2013). Although network centric systems for emergency management are thus far mainly used for the exchange of information between the operational and higher levels of the incident command systems (tactical and strategic), the network centric exchange of information between operational actors is assumed to increase performance and might be enabled by the increased adoption of mobile technology. The findings on the uneven distribution of information indicate that when network centric systems are in place, streams of information will most likely run from few to many, or that few actors contribute information while many consult the system in search for information. This raises the question whether key actors will actually be supported by network centric systems, or whether such systems only give them additional tasks that they have to perform in addition to their already comprehensive range of duties. When key actors are overburdened, processes like self-imposed isolation and circling around key actors are likely to emerge as well in the information systems that enable network centric operations. Our findings contribute to understanding how emergency response actors cope with the realities of an uneven distribution of information, and thereby provide relevant insights for the design and workings of network centric organizations.

The findings on emergent coordination in the field challenge common theoretical views on the role of coordination and command and control during emergency management. Problems in emergency response are often attributed to a lack of coordination and emergency response networks are supposed to be well-coordinated to perform well (Quarantelli, 1988; Kapucu, 2005; Waugh Jr & Streib, 2006). We found that the relation between the amount of communication and performance is negative, especially once the response to an emergency has started and response tasks are being executed. More communications and coordination are related to inefficiencies and difficulties in operational emergency response, especially during the intermediate response phase and high performing on-scene command teams are characterized by low levels of communication and coordination in the field. This supports findings of previous research that suggest that operational emergency response is essentially 'working together apart' (Helsloot, 2008; Groenendaal, Helsloot, and Scholtens, 2013).

The finding that collective sensemaking is at the core of emergency management performance is in line with prevailing theoretical views (Thomas, Clark, and Gioia, 1993). Our observations add three premises to existing theory. First, concerns can be pushed and prioritized through disruptions of the processes of developing shared situational understanding and situational assessment. Second, the degree of attention for specific concerns is the outcome of the interactions between individual actors and team leaders. Individual actors push their concerns and team leaders react, causing concerns to receive more or less attention. And third, collective sensemaking is influenced by actions that take place when emergency response shifts from the field to on-scene command team meetings (see the explanation of transition processes in 8.1). Actions and interactions in these transition periods are introduced in our revised conceptual framework as transition processes. The findings with regard to transition processes are in line with previous findings in the literature on decision-making in general, especially the literature on agenda setting. Reporting to information managers prior to team meetings resembles the notion that formal agendas create the setting of the arena in which policies are formed and decisions are made (Kingdon & Thurber, 1984; Pollack, 1997). The observations on actors pushing their individual concerns and forming coalitions to promote concerns resemble similar traditional notions of advocacy of concerns by coalitions (Sabatier, 1988). These findings suggest that insights from more traditional public administration research, especially multi-actor decision-making and decision-making processes, are more useful for understanding emergency response and emergency management performance than reflected by the current emergency management literature.

Emergency decision-making receives ample attention in emergency management literature, often in terms of naturalistic decision-making (NDM) (Flin, 2001). Our findings do not relate to the traditional premises of NDM about recognition primed decision-making but support the outcomes of research on NDM in team settings that claims that decisions are the result of interactions within a team (Lipshitz *et al.*, 2001). Our findings suggest as well that decision-making – in the shape of choosing between alternatives on the basis of substantial arguments – is very limited during emergency response. Prioritizing response tasks is primarily the result of interactions between response actors without a deliberate consideration of several options. The only clear deliberations were observed in relation to dangerous situations and the risk to which emergency responders were exposed. In these situations, it was either team leaders that made a final decision or the response was characterized by indecisiveness and non-decisions when decisions were postponed to later moments.

8.4 The inner workings of resilience

We describe in the introduction in chapter one and the literature review in chapter two how resilience is commonly presented in the literature on emergency management and infrastructure reliability as a system property without further explanation of the processes through which resilience comes about. However, recovery of disrupted socio-technical systems such as infrastructures does not just happen as an inherent system characteristic. Recovery is the product of the actions of emergency response actors that execute recovery related response tasks as part of a larger, comprehensive emergency response effort. This makes that infrastructure resilience cannot be perceived as an inherent system property but as a *tour de force* that is achieved (to a varying degree) every time a system is disrupted.

Our research findings confirm that in order to understand infrastructure resilience it is necessary to go beyond looking at the system from the outside and to explore the processes that take place inside the system when it is disrupted. Whether infrastructure recovery happens and how fast – the degree of infrastructure resilience – depends on the actions and coordination of operational emergency response actors. When it comes to infrastructures, the actions and interactions of emergency response actors form the inner workings of resilience. These inner workings primarily take place in the response arenas that emerge at the remote locations where disruptive emergencies occur.

Response arenas instead of command and control

Our empirical research shows how operational emergency management is characterized by cooperation between emergency response actors as well as struggles between actors to increase attention for their specific concerns. Operational emergency response is thereby found to be both a collaborative as well as a competitive effort. We witnessed operational emergency management predominantly as an interplay between more or less autonomous agents and only occasionally as the operation of a centrally controlled structure of rule or command following agents. These observations lead us to conceive of operational emergency response as an arena in which players simultaneously have to cooperate and form alliances and engage in struggles to reach their objectives.

The setting of emergency response arenas is determined by the characteristics of an emergency situation. The number and type of actors required at the emergency scene, the response tasks that need to be performed, and how tasks, information and expertise are spread over actors involved in the arena, depend on the specific nature of the emergency at hand. Most actors in a response arena have their own specific responsibilities and objectives. Team leaders are responsible for guarding the efficiency and effectiveness of an emergency response as a whole. Response arenas are relatively unstructured. Few formal rules apply and the acts and strategies that response actors follow are manifold. The agreement that the first arriving officer takes the lead over the initial response before a team leader arrives and the fact that on-scene command team meetings are structured in accordance with the 'BOB' model (chapter two) are informal rules that are usually adhered to. Beyond these agreements, the interaction between response actors is more or less open and our research shows that actors use this discretionary space to interact in divergent ways.

Emergency management performance and, as part of that, infrastructure resilience are the result of the combined actions of actors in the response arena. Emergency response has multiple objectives and the effectiveness of emergency management must therefore be assessed on multiple criteria. Actions of emergency response actors and interactions between emergency response actors determine how specific emergency management objectives are prioritized and reached or not. So whether or not the recovery of disrupted infrastructure systems is prioritized at the operational level is determined by interactions between response actors. Actors that have infrastructure recovery as a concern (usually the infrastructure operator and local authorities) have to draw attention to their concern and compete with other objectives to be on the response agenda.

The perception of operational emergency management as a multi-actor arena is different from the command and control perspective that is often used to analyze emergency response. As emergency response is becoming more networked instead of hierarchical and more and different actors become part of the response, the command and control perspective of planning, decision-making and leading the response is likely to become less useful and the multi-actor perspective is likely to become increasingly relevant. Using the research outcomes and taking on this multi-actor perspective we identify a number of recommendations on how to improve emergency management performance and increase infrastructure resilience in the next chapter.

Epilogue
Recommendations and future research

The technological complexity of emergency situations is increasing, the number of actors that are part of emergency response is growing, and the economic impact of disruptive incidents is on the rise. In the light of these trends, we provide several practical recommendations and questions for future research. The recommendations are composed for researchers that try to understand how resilience comes about, for practitioners and emergency services that try to be (more) resilient, for those who design and develop virtual reality exercises and others that prepare for emergency situations and try to improve emergency management effectiveness. The questions for future research are drafted for researchers of incident, emergency, and crisis management and for methodologists and others who try to obtain insight in how we can understand and reflect upon emergency management and analyze and assess behavior in emergency management exercises.

The first section evolves around the question how to be resilient? We discuss several strategies that emergency response actors can follow to increase emergency management effectiveness and reflect upon the possibilities of team leaders and other leading actors to manage emergency response arenas and steer emergency response in a desired direction. Section two focuses on how emergency response can become more resilient. We discuss how resilience can be addressed in (virtual reality) emergency management exercises and how emergency response actors can be prepared for different roles during the response to an emergency. The third and last section focuses on the methodological issue of how to identify resilience. We discuss how emergency management research can become more systematic and how the combination of analytics and expert observations can help to improve the analysis of emergency management processes, for research and for the analysis and assessment of emergency management exercises.

How to be resilient?

How can disruptive emergencies be managed efficiently and effectively with the right amount of attention for infrastructure recovery? Based on our understanding of operational emergency management as an arena in which multiple actors cooperate and compete to reach their objectives, and the response processes identified by this research, we suggest three directions for improvement of emergency management performance:

1. Stimulate the good, repress the bad, and steer towards desired outcomes.
2. Cope with complexity and crowdedness.
3. Manage response arenas to increase infrastructure resilience

Stimulate the good, repress the bad, and steer towards desired outcomes

Our empirical investigations reveal several practices in operational emergency response that form instant opportunities to improve operational emergency management performance. Processes that contribute positively to performance – the organization of field meetings, field coordination in functional subgroups, instigation of bilateral and multilateral coordination by team leaders, and agenda control by team leaders – should be encouraged and if necessary extended to improve the efficiency and effectiveness of operational emergency response. The organization of field meetings is common practice in the Dutch incident command system but further research on the inner workings of field meetings is desirable as our research shows that the duration of field meetings, the involvement of different actors, and the contribution of field meetings to situational understanding and performance vary. Forming functional subgroups around multidisciplinary tasks is also a common practice that can be maintained and enforced by team leaders that instigate coordination between the right actors and actors themselves to search for the right actors to collaborate with. Agenda control during team meetings can be improved by giving it additional attention in the training and education of team leaders and making it an explicit topic in post-exercise evaluations.

Processes that reduce the efficiency and effectiveness of emergency response – isolation from communications and holding on to experts by key actors, circling around key actors, coordination by non-key actors and in non-functional subgroups, and delegation of key tasks to subgroups or individual actors – need to be limited or omitted to increase the efficiency and effectiveness of operational emergency response. The fact that information is unevenly distributed over emergency response actors cannot be altered, but how actors deal with the uneven distribution can be improved. Self-imposed isolation of key actors is effective as long as alternative ways to spread information are used. This can be done through field meetings and perhaps by technological solutions like mobile information systems that make it possible for key actors to share information with the larger response organization. In the latter case, key actors must be aware of the information need of other actors. Holding on to experts can be avoided by making experts aware of their value to the larger response organization so they can avoid getting stuck on one specific actor. The emergence of non-functional subgroups can be limited by placing restrictions on the presence of actors on an emergency location. As our research shows that involvement of non-functional actors and presence of actors with no immediate tasks hampers response effectiveness, actors should only be at an emergency scene when they have tasks to manage and otherwise keep their distance.

The identified processes that adjust emergency management performance and shift attention to specific objectives – self-imposed isolation from coordination by key actors, reporting to the information manager prior to meetings, actor prominence and inconspicuousness, the disruption of developing situational understanding, and forming coalitions – should not necessarily be extended or discouraged but emergency response actors, and especially team leaders, should be aware of the effects of these practices. As the objective of emergency management is to deliver an efficient and effective overall response, performance adjusting processes should only be allowed to continue when they correct tasks that dominate the response or support tasks that are underexposed and not to reinforce tasks that are already at the core of the response and reduce overall response effectiveness.

Cope with complexity and crowdedness

Emergency management is characterized by increasing technological complexity of infrastructure systems, growing numbers of actors involved in emergency response, and more pressure to recover infrastructural systems rapidly. These trends alter the effects and importance of some of the emergency management processes identified.

Increasing technological complexity makes that the importance of agenda control is growing. Technological complexity makes that more technological issues turn up at the response agenda. Without claiming that important details should be set aside, we argue that discussions on technical issues should be kept out of multidisciplinary coordination as much as possible. Increasing technological complexity also makes that functional subgroups have to be extended with technological experts. Such technology oriented subgroups will have to find ways to maintain a balance between solving technical issues and reaching immediate response objectives.

The increasing number of response actors that is present at emergency scenes is affecting many of the emergency response processes identified. Organizing field meetings and agenda control are two performance enhancing processes that become more challenging when more actors become part of the response. The organization of field meetings becomes increasingly important as a method for key actors to inform all actors present on the scene. Agenda control is becoming more important when more actors push their concerns, either individually or by forming coalitions. All performance decreasing processes identified in our research are likely to be influenced by increasing numbers of actors. Self-imposed isolation from communications is becoming a more attractive option for key actors as they are flooded by information requests from the many actors circling around them. Formation of non-functional subgroups becomes more likely as well as coordination by non-key actors. Performance adjusting processes are also affected. Self-imposed isolation from coordination by key actors is becoming a more attractive course of action as coordination is more intensive with many actors present and therefore more difficult to combine with individual tasks. Disruptions of developing shared understanding are likely to become more numerous when more actors come to the scene that are unaware of emergency response practices and agreements. Forming coalitions is also more likely to happen, making it more difficult for team leaders to keep concerns from the agenda. Nearly all of the actions and interactions between emergency response actors that determine emergency management performance are affected by the changing nature and conditions of operational emergency management. The effect is, in general, that the impact of processes on performance is reinforced, making insight in the workings of these processes increasingly relevant.

There are two aspects of emergency management that are especially important for emergency management performance when the number of actors present on an emergency scene increases:

- The need to *orchestrate* emergency response efforts grows. The task of first arriving officers and team leaders to orchestrate the response becomes increasingly stressful and asks more and more of their multidisciplinary emergency management capabilities. This also means that it becomes increasingly important for response actors to show discipline and restrain from communication and coordination if not necessary. If emergency response requires working together apart (Helsloot, 2008) actors must avoid unnecessary interactions but when collaboration is needed they must follow instructions from the orchestrating actor or team leader and become an integral part of the response. Such a switch in attitude might be unusual for autonomous actors that collaborate without formal arrangements or hierarchy (Boin *et al.*, 2006; Boin & Bynander, 2015; Groenendaal & Helsloot, 2015).
- Developing situational awareness becomes more difficult when more actors are present. This is especially the case when actors have partial, and potentially deviant views on the emergency situation. Developing shared situational understanding requires the exchange of precise information – like the type of victims or the severity of damage to cars involved in a collision – and therefore requires conversations between actors and not just the sending of information. Even a small increase in the number of actors in the emergency response organization is likely to be accompanied by a substantial increase in the amount of communication.

Technological solutions are often presented to accommodate the increasing demand for communication. Network centric operations and the IT platforms that enable network centric information exchange are used to integrate views and develop a common operational picture (Wolbers & Boersma, 2013). Current network centric systems are of limited relevance when it comes to the operational level operational emergency response because operational actors are primarily providing information on the emergency situation to higher levels of the incident command system and receive little information or guidance in return. However, technological innovations might change this. Mobile devices, helmet cams, and connected machines might help to exchange information more effectively and efficiently between actors at the operational level. Although technological advancements are expected to change the response arena, the currently observed interactions and issues are likely to remain relevant. Processes like self-imposed isolation and circling will remain relevant, also when the exchange of information becomes more digitalized. In any case, the efficient and effective exchange of information to increase situational awareness and develop a common operational picture for many actors will require extensive training and experience with emergency management processes. Unless actors are thoroughly familiar with the information needs of others, they will not be able to provide relevant information without a two way conversation. This results in abundant communications in which the processes we describe will only become more influential.

Manage response arenas to increase infrastructure resilience

The growing pressure to restore infrastructure functions rapidly makes performance improving processes particularly important. Agenda control is especially important to give infrastructure recovery the right position at the response agenda. Performance decreasing processes should obviously be avoided to restore infrastructure functions quickly, particularly the delegation of key tasks to subgroups or individual actors. With the increasing importance of infrastructure recovery, recovery operations are more and more likely to become a core emergency response issue instead of a peripheral response task.

Since we are especially interested in infrastructure recovery, we explain how we think performance of this specific objective can be increased. It is important to emphasize that infrastructure recovery must get the *appropriate* amount of attention in emergency response. It should not be neglected or treated as a minor issue but neither become dominant (we witnessed a few occasions on which operational emergency responders spend a considerable amount of time discussing infrastructure recovery instead of firefighting, evacuation, or traffic management). However, in general, the recovery of infrastructure receives less attention than traditional tasks like firefighting or medical care. We therefore focus on strategies to increase attention for infrastructure recovery. Attention for infrastructure recovery can be increased by reinforcing the position of infrastructure operators and local authorities in the response arena. This can be done by making them report out on recovery related issues prior to team meetings and stimulating them to speak up in the meetings. If the impact of an infrastructure disruption is especially large it must become part of the situational understanding of the team. This can be done by forming coalitions with multiple actors concerned with infrastructure recovery that jointly push their concerns and bring the issue under the attention of key actors in the response. When key actors isolate themselves from communication and coordination, infrastructure operators and local authorities should make sure that infrastructure recovery is brought up during field and on-scene command team meetings and that team leaders are aware of the fact that key actors do not look after the response as a whole, and the recovery of the disrupted infrastructure in particular.

Future research into resilience

We provide three questions for future research into resilience, focusing on the contribution of operational emergency response:

1. What procedures provide an efficient way to exchange information and develop shared situational understanding in the operational response to emergencies when many actors with different organizational backgrounds are involved?
2. How can emergency response actors jointly prioritize emergency response objectives and manage the amount of attention that is paid to specific concerns and objectives during operational emergency response?
3. How can emergency response actors assess the importance of technological issues and determine the appropriate amount of attention that must be paid so technological issues during on-scene command team meetings or field meetings of multidisciplinary subgroups?

What procedures lead to efficient information exchange?

The question what procedures provide an efficient way to develop shared situational understanding is relevant because of the growing number of emergency response actors present at emergency locations and the differences between actors in terms of expertise, situationally relevant information, and tasks to manage. Efficient sharing of information under these conditions is challenging. Our research shows that the organization of field meetings can lead to better situational understanding. However, further research on the inner workings of field meetings is necessary since we also show that the duration of field meetings, the involvement of different actors, and the contribution of field meetings to situational understanding and emergency management performance vary. Moreover, it is necessary to study how information is exchanged beyond field meetings to understand how multidisciplinary subgroups develop shared situational understanding. To increase resilience, we must understand how multiple actors at an emergency scene can exchange information efficiently and effectively.

How to jointly prioritize response objectives?

Operational emergency response has multiple objectives, depending on the characteristics of an emergency, the location of an emergency, and (local) policy preferences. Our research shows how the choice of objectives to prioritize is often not deliberately made. The choice of objectives seems to be the result of the preferences and capabilities of individual emergency response actors and the interactions between different emergency response actors. This makes that the operational emergency response can be inefficient and aimed at the 'wrong' objectives as seen from a larger, comprehensive emergency response. To steer emergency response in a desired direction, we must understand how the amount of attention for specific concerns and objectives in emergency response can be managed. Our inquiries reveal several performance adjusting processes that shift the attention from one emergency response objective to another. Future research must refine these insights to give team leaders and other leading actor insights in how they can jointly steer emergency response objectives when necessary.

How to assess the importance of technological issues?

Technological issues become more prevalent during emergency response with the growing technological complexity of infrastructures. Technological issues deserve ample attention as their impact on the emergency response can be significant. At the same time, it is necessary to make sure that technological aspects do not wrongfully dominate response efforts. Determining the appropriate amount of attention that should be paid to technological aspects is particularly challenging because that are generally only a few actors that understand the impact and consequences of technological issues. To organize efficient and effective emergency response, we must understand how technology experts and other emergency response actors can decide on the importance of technological issues together.

How to become more resilient?

The organization of virtual reality exercises as part of education, training, and exercise programs has become common practice for Dutch emergency services throughout the last decade. Given this trend it is relevant to ask how virtual reality exercises can be designed to deliver the required competencies for multidisciplinary emergency response –infrastructure recovery in particular – more effectively. The aim of virtual reality exercises is to improve emergency response effectiveness and make emergency services better prepared for emergency situations. Multidisciplinary virtual reality exercises aim specifically at improving communication between emergency responders, the joint organization of response tasks, and coordination during emergencies. Our experience with virtual reality exercises and the insights from this study of emergency management performance provide directions for designing effective virtual reality exercises that contribute to infrastructure resilience. We provide four specific recommendations.

1. Focus on emergency management processes *and* achievements.
2. Assess emergency management performance at multiple levels.
3. Address the orchestrating role of key response actors.
4. Make emergency response actors understand how the focus of emergency response switches between emergency management objectives.

Emergency management: processes and achievements

The focus of virtual reality exercises lies on improving interactions between response actors during the coordination of emergency response tasks. Addressing interactions contributes to emergency management effectiveness but leaves several of the challenges revealed in this study aside. Our research shows how communications and interactions between emergency response actors follow different patterns around emergency management processes that, at their turn, lead in different ways to emergency management performance. This implies that emergency response must be improved in terms of communications, response processes, and achieving objectives in order to increase resilience. A logical order to evaluate these topics is to start with interactions and communications as these form the most explicit and visible behavior during exercises, then proceed with response processes and task coordination that are based on interactions, and finish with task effectiveness and goal achievement. The list of actions and interactions that influence emergency management performance (chapter eight) can serve as a point of departure for developing a comprehensive evaluative scheme for emergency management processes. Explicit attention for task performance and the achievement of objectives helps emergency response actors to focus on results and forces them to reflect on how they cope with tensions between managing their own individual tasks and contributing to the larger response organization.

Multilevel emergency management performance assessment

Operational emergency management performance is multi-layered and must be assessed as such. Many approaches to team performance scores, including the temporal framework of team performance of Marks, Mathieu, and Zaccaro (2001) that is adjusted in this study to analyze emergency management performance, perceive performance as a one dimensional concept; performance is either high or low. Our research shows that performance is a multi-layered concept in operational emergency management. Team performance includes characteristics of the processes through which response actors communicate and coordinate, task effectiveness and the achievement of objectives, and the satisfaction of response actors with their own acts and decisions and those of others. Moreover, task performance can be assessed at the level of specific response tasks, individual response actors, multidisciplinary subgroups, and on-scene command teams as a whole. To do justice to the complexity of emergency management performance, it is necessary to use performance composites that include different aspects of performance and adopt a multilevel approach that addresses differences between performance of specific actors or subgroups and the collective performance of the response as a whole. A multi-aspect, multilevel approach to emergency management performance improves the quality of evaluations of virtual reality exercises and helps response actors to make the distinction between their satisfaction with response processes, the outcomes they achieve, their individual performance, and the performance of the larger response organization.

An orchestrating role for key response actors

Team leaders and key actors must learn how to orchestrate emergency response to increase response effectiveness and resilience. In order to get a grip on the efficiency and effectiveness of emergency response and the prioritization of response objectives, team leaders or other key actors, need to extend their role as director or orchestrator of the operational emergency response. Team leaders have to manage competing objectives during on-scene command team meetings and to take and maintain control over the meeting agenda. With more actors involved in meetings and more opportunities for the formation of coalitions, a more directive role of team leaders is necessary. Extending the role of key actors also includes a leading role in emergency coordination in the field, for example in leading field meetings. This requires additional competencies such as dealing with frontline units that are difficult to control (Groenendaal, 2015) and striking the right tone when intervening with emergent coordinative efforts (Boin & Bynander, 2015). To increase resilience, virtual reality exercises must address these competencies of team leaders and all emergency response actors that potentially become emergent leaders as a result of the characteristics of an emergency scenario.

Shifting the focus of emergency response

Emergency response actors must be familiar with performance adjusting processes to steer the emergency response and to reach desired objectives. Our research shows that self-imposed isolation by key response actors and coordination by non-key actors decreases emergency management performance. This outcome implies that key actors have to take up a coordinative role in the field, despite their monodisciplinary responsibilities. The orchestrating role in field coordination includes the formation of multidisciplinary subgroups with the right composition to manage multidisciplinary tasks, managing (extensive) field meetings to deal with an uneven distribution of tasks and information, and handling self-imposed isolation by key response actors and the capture of experts by a single response discipline. Increasing the familiarity of response actors with these emergency management processes, and the other processes identified in this study, helps to reinforce performance enhancing processes, counteract performance reducing processes, and make actors aware of performance adjusting processes that change emergency response effectiveness in their advantage or disadvantage. To control emergency management performance at increasingly crowded emergency scenes, the tools for control must be improved, either through the empowerment of key actors or by increasing the (self-)control of other response actors. This links to what Pettersen and Schulman refer to as precursor resilience, which is "keeping operations within a bandwidth of conditions and acting quickly to restore these conditions if necessary" (Pettersen & Schulman, 2016). Emergency exercises should aim to increase the familiarity of emergency responders with the effects of emergency management processes on performance, the risk of organizational drift in the emergency response organization, and the methods to establish and maintain precursor resilience to provide them the control they need to steer emergency response towards desired objectives.

Future research into becoming more resilient

We provide two suggestions for further research into virtual reality exercises on basis of our experience and insights:

1. How can virtual reality exercises be focused on specific emergency management concerns and objectives?
2. What analytical and visualization methods are required to provide emergency responders insight in emergency management processes during and after virtual reality emergency management exercises?

How to focusing on specific concerns and objectives?

The designers of emergency management exercises tend to write extensive emergency scenarios that include many response tasks and objectives. This is done to give a challenge to all emergency response actors that take part in an exercise. The exercise developers of the Westerschelde Tunnel scenarios, for example, introduced additional tasks to challenge actors that had to wait before they were allowed access to the emergency scene in the tunnel. This makes sense from the learning objectives but jeopardizes the authenticity of exercise scenarios. How to design exercise scenarios that focus on specific themes, concerns, and objectives without being relevant for a few actors alone, is therefore highly relevant. We think that increasing insight in the roles and behavior of peripheral emergency response actors can be a useful point of departure. Non-key actors might not be at the core of an exercise but their actions and their interactions with key actors are of influence on the success of the emergency response. Explicitly addressing the role of non-key actors and the effect of their actions on emergency management processes and performance scores may form a first step to focus emergency management exercises on specific concerns and objectives.

What analytics and tools are required to gain insight in emergency management processes?

Emergencies are hectic and chaotic events and emergency responders have little time to reflect on their actions and decisions. Models have been developed to support emergency responders and exercise evaluators with structuring the reflection on actions and decisions (Lamb *et al.*, 2014). We think that, in addition to such models, emergency responders will benefit from tools that help them recognize emergency management processes like self-imposed isolation, claiming experts, or circling around key actors. Recognition and notification of such processes is useful for post-exercise evaluations and for emergency responders in action because insight in emergency response processes gives them an opportunity to steer and improve the response *during* an emergency. Developing tools for (direct) feedback on emergency management processes requires practical tools to provide feedback, like dashboards, pop-up notifications or sound indicators, and analytics to identify emergency management processes. Both need to be developed to support emergency responders in reflecting on their actions and decisions.

How to identify resilience?

It is notoriously difficult to make resilience explicit and to find ways to identify, assess, and measure resilience (de Bruijne, Boin, and van Eeten, 2010). We offer four recommendations on how to operationalize and identify resilience:

1. Move beyond anecdotal evidence.
2. Use theoretically informed analytics to identify resilience.
3. 'Zoom-in' on specific situations to obtain insights in how resilience comes about.
4. Combine analytics and observations to obtain better insights than those that can be obtained by using individual methods.

Move beyond anecdotal evidence

The literature on emergency management and resilience is primarily based on case studies and anecdotal evidence (Moynihan, 2009). The account developed in this study shows how emergency management research can be systematic by combing research methods. A quantitative approach helps to create a systematic overview and identify areas of interest (including positive cases like high-performing response organizations that are rarely studied) and a qualitative method provides detailed descriptions of actors in action and their interactions. A combined approach of analytics and expert observations forms a powerful strategy to identify and explain the presence or absence of resilience and has potential to improve research into resilience and learning during and after emergency management exercises. To identify resilience, it is necessary to be systematic and profound.

Use theoretically informed analytics to identify resilience

Emergency response involves many actions, decisions, and interactions between response actors. To identify resilience it is necessary to identify the crucial moments in a response that determine emergency management effectiveness. What analytics can be used to identify such moments? Besides for research, communication network analysis has value as a (real-time) metric to monitor and assess team and emergency management performance. We provide several recommendations for using communication network analysis to address and assess resilience in research and *during* exercises or in post-exercise evaluations.

Communication network analysis can be used to identify problematic episodes in emergency response. Our a-priori expectation for the analysis of communication networks was that the amount of communication between emergency response actors would be positively associated with emergency management performance. That the density of communication networks and the centrality of actors within communication networks are negatively associated with performance did therefore come as a surprise. Observations on teams and actors involved in extensive communications showed that variation in the amount of communication is primarily due to non-functional and inefficient communication. These findings changed the role of communication network analysis in our research from a method to identify positive coordinative efforts to a tool to trace inefficiencies and redundant communications. In other words, communication network analytics help to identify a lack of resilience.

In our analysis, we learned how to use communication network metrics to identify resilience. A binary approach to communication networks only traces whether communications between two actors take place or not and does not prove useful to identify effective coordination because almost all actors speak to one another at some point during an emergency response. A weighted approach in which the duration of communication is taken into account is the only way to differentiate and provide an accurate account of the amount of communication within a team. However, in weighted networks, effective communication that contributes to emergency management performance gets lost between less relevant or ineffective communication. The negative, distractive effect of non-task related communication becomes stronger as more non-task related communication takes place between actors. A cumulative approach to create weighted networks does therefore only allow a researcher to trace the effects of abundant communications and not to identify more subtle interactions. Weighted network analysis provides a more accurate account of communications during emergency response than binary network analysis and helps to identify trouble or a lack of resilience.

Can more advanced communication network analysis metrics *identify* effective coordination? Our findings show that effective coordination of emergency response tasks does not require much communication. Coordination is more complex than communication and using communication as a proxy for coordination does not generate the desired insights. Our research shows that analyzing communication can help to identify issues (both positive and negative) with regard to coordination. Understanding how emergency management performance comes about cannot be done on basis of behavioral measurements alone but requires qualitative observations as well. We are not the first to stress the importance of qualitative methods to strengthen insights from network analysis. Uhr & Johansson (2007) analyzed ‘importance’ of actors through their degree and betweenness centrality in a network. The researchers decided at some point to ask actors about the ‘importance’ of others to identify key actors because the quantitative proxies did not provide relevant insights. Our investigations show that what goes on within a communication network is complex, and statistically significant relations between network characteristics identified with advanced network analysis metrics and performance outcomes cannot be interpreted without further qualitative investigations.

To what extent are advanced communication network analysis metrics able to *explain* effective coordination? The correlations that are found between weighted betweenness centrality and weighted in-degree centrality during specific stages of emergency response and emergency management performance suggest that more advanced network metrics will be able to identify effective coordination. There are possibilities for applying more advanced metrics (see for example Zenk, Stadtfeld, and Windhager (2010)) and metric composites. However, if such metrics are found to identify effective coordination, the explanation for why the patterns of communication traced by the metrics result in high performance still requires more in-depth, qualitative analysis of the interactions between actors. Independent from how sophisticated network analysis metrics become, qualitative insight in communications, the characteristics of an emergency scenario, and theoretically informed explanations remain necessary to explain what constitutes effective coordination.

'Zoom-in' for insights

Communication network analytics help to identify crucial moments during emergency response but cannot explain why emergency management becomes effective or not. Explaining emergency management effectiveness requires a qualitative approach. Video recording via time synchronization of five cameras made that all interactions between emergency responders where captured during our exercises. The resulting footage was extensive and detailed and analysis with the Transana video analysis software allowed us to focus on selected fragments and transect the interactions sentence by sentence. The analysis produced a detailed account of operational emergency response that enabled us to explain why certain actions and interactions lead to an increase or decrease of emergency management effectiveness.

The video recordings proved especially useful to study the actions and interactions of emergency response actors in their context. The ability to move back and forth through conversations made it possible to understand how actors try to arrange and organize tasks and to trace the origins and effects of choices. The usefulness of the video-observations for our research shows that the relatively limited use of video-ethnography in academic research is undeserved (Heath & Hindmarsh, 2002; Angrosino, 2007). The use of video observation is especially relevant in crisis settings in which direct observational research is normally impractical and sometimes unethical. Video-observation in traditional crisis exercises is practically challenging due to the geographical dispersion of actors and continuous action. The rise of virtual reality exercises provides an opportunity for video-based research and video observations might become a relevant tool for exercise evaluations. Video-fragments, handpicked or selected with support of theoretically driven communication network metrics, can help emergency response actors to reflect upon important episodes and enable expert observers to substantiate their observations.

Combine analytics and observations

Using analytics and experts observations together enables researchers, emergency responders and exercise evaluators to obtain better understanding of why emergency response becomes effective or not. Communication network analysis and (video)-observations have limitations as individual methods but mixing the two methods proved a powerful strategy to gain insights with regard to our research questions. Communication network analysis with the currently available metrics proves unsuitable to pinpoint effective coordination but helps to trace difficult exchanges and ineffective communications. Video-observations are time consuming and difficult to perform systematically but enable the development of a detailed account of coordination during specific moments of emergency response. Both approaches create incomplete but useful accounts of what goes on during emergency response. Combining the accounts generates a comprehensive picture that is worth more than the two individual accounts alone.

Combining communication network analysis and video-ethnography proves beneficial in two ways. First, communication network analysis helps us to focus on interesting moments and interactions during emergency responses and to filter an extensive amount of observational data. Communication network analysis allows us to obtain a global overview of communicative behavior and makes it possible to select specific (pairs of) theoretically relevant cases. Second, video-observations help to explain patterns in communication networks and raises new questions for network analysis. Video-observations generate hypotheses that required further study with communication network analysis to see whether the observed practices systematically account for differences in emergency management performance. The combination of the two methods helps to understand what goes on during emergency response and enforces in-depth insights by linking them to structural differences between teams or actors. Combining the methods makes that qualitative, in depth research becomes data-driven and quantitative analysis becomes theory-driven.

Future research into the identification of resilience

Theoretically driven analytics are not only relevant for research but can also be used for feedback during, and reflection after, (virtual reality) emergency management exercises. The insights and experience gained in this study lead us to suggest two questions for future research:

1. What advanced (communication) network analysis metrics are able to identify emergency management processes and effective coordination during emergency response?
2. What visualizations or other representational techniques are appropriate to provide emergency responders with valid and insightful feedback on

emergency management processes during and after emergency response exercises?

What advanced metrics are able to identify resilience?

Our research suggests that advanced network analysis metrics are capable of identifying effective coordination during emergency response. The techniques for analyzing social networks are advancing rapidly and new insights in this field might prove useful to identify effective coordination in emergency response communication networks. Applying findings from (social) network analysis research to emergency management exercises can start with trying to identify emergency management processes, like the ones identified in this research. When analytics are found that help to pinpoint actions and interactions such as the claiming of experts, circling around key actors, or self-imposed isolation, the analysis of resilience can make a next step in becoming more systematic. Also, advanced real-time metrics might help emergency responders reflect upon their actions and adapt their behavior when necessary to increase the effectiveness of emergency response.

What representational techniques provide insight?

Using advanced analytics for feedback and reflection during emergency management exercises and in post-exercise evaluations requires reliable and insightful representational techniques. The development of dashboards that reveal how the response to an emergency is progressing and that provide insights in the quality of emergency response is challenging. We provide three directions for future research.

First, dashboards must be sensitive to the stage in which the response to an emergency resides. We used a three stage approach for our analysis. Further temporal differentiation might provide more insights, especially in the initial stage of emergency response when so much is happening that further differentiation is likely to identify relevant processes. What constitutes a suitable level of temporal differentiation for the initial stage of emergency response and emergency response in general requires further research. A key insight from our research is that it matters when certain actions and interactions take place and this implies that dashboards for the analysis of emergency response should be time-sensitive as well, applying different analytics at different stages of emergency response.

Second, network analytics can initially be used to identify problems. Our research shows that much communication is systematically associated with low emergency management performance. Developing a dashboard for emergency management performance can therefore start with tracing problematic episodes by simply accumulating the amount of communication that takes place between emergency response and within an emergency response organization as a whole. Once the techniques for 'tracing trouble' have matured, we can continue with developing analytics that help identify effective emergency response.

Third, research can focus on how theory, analytics and practical applications enforce each other. The development and implementation of dashboards goes hand in hand with the development of analytics and increasing understanding of emergency management and resilience. Dashboard outcomes provide insights on the validity and usefulness of analytics. And the outcomes of analytics provide insights that help to understand how emergency management effectiveness comes about. Moreover, understanding how effective emergency response comes about is of influence on how to develop useful dashboards. Research that focuses on the possibilities to combine state-of-the-art theoretical insights, analytics, and practical applications, will enable us to boost our understanding of how to respond to disruptive incidents so we can work towards a more resilient society.

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Summary

Critical infrastructure resilience

The national, economic and ecological well-being of industrialized nations depends on the reliable functioning of infrastructure. That is why policy makers have coined the term critical infrastructure. The reliability of critical infrastructures is affected by increasing technological and organizational complexity. Integration of ICT components in infrastructures, dependencies between infrastructures, and the distribution of design, management, and maintenance over different organizations cause critical infrastructures to become more complex. The reliable functioning of critical infrastructure can only be maintained when the ability to deal with this growing complexity increases as well. This ability is not only a matter of comprehensive risk management. The effectiveness of the strategy of anticipating risks and trying to prevent incidents is limited in complex systems. Managing risks in complex systems mainly requires resilience, the ability to cope with incidents and to recover a system quickly.

Resilience is a popular concept. The ability to recover quickly after disturbances is a desirable feature that can be applied to many systems, from organizations and local communities to cities and countries. What resilience means, what has to happen within a system to make it recover quickly, is often left unspecified. This study focuses on the resilience of critical infrastructure. The response to incidents that disrupt critical infrastructure (emergencies like major accidents, malfunctions, or deliberate attacks) consists of more and more aspects because of increasing complexity. The number of objects that can fail or become a target increases, the number of tasks that must be performed in response to an incident increases, and the need to coordinate the response increases. Effective emergency response is a matter of the efficient and fast performance of a multitude of tasks, and the achievement of a variety of objectives. Given this context, we ask what critical infrastructure resilience is. What is needed to manage incidents quickly and effectively and to restore critical infrastructures after disruptions? Can we define patterns or a collection of distinct events and actions that indicate what infrastructure resilience is?

The purpose of this research is to give substance to the concept of critical infrastructure resilience. We do this for three reasons. First, it is necessary to develop a concrete conceptualization of critical infrastructure resilience to provide substance and content to the policy discussion on resilience. Second, it is necessary to better understand the effects of increasing complexity on the ability to manage incidents and disruptions of critical infrastructure. Much of what we know about effective emergency management does not include the rapidly increasing technological complexity of infrastructure and the multitude of actors at incident sites. And third, it is necessary to understand the factors that influence the effectiveness of incident response. Identifying and understanding these factors is necessary to develop more effective emergency management and thereby increase the resilience of critical infrastructures.

This study focuses on two questions: i) how do emergency response actors coordinate multiple emergency management objectives and procedures, and (ii) how does the way they do this determine emergency management performance?

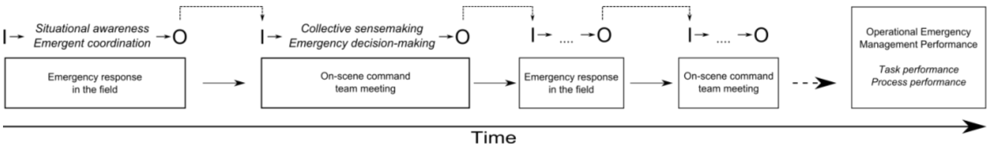
To discover influential factors for operational emergency management performance, we consider emergency response in terms of processes and performance. We develop an analytical framework that combines different processes and concepts that help explain variation in emergency management performance (Chapter 2). Performance is analyzed with a focus on the execution of mono- and multidisciplinary tasks and the achievement of results. We study operational emergency response during virtual reality exercises (chapter 3). We choose for virtual reality exercises because they allow us to study emergency management processes and interactions between actors systematically and from a short distance. We use a research design in which we combine network analysis of communications between actors with a qualitative analysis of video observations (Chapter 4). The combination enables us to systematically develop a comprehensive account of operational emergency management. The empirical research consists of three parts. First, we describe and analyze emergency management performance (Chapter 5). Second, we describe the results of the communication network analysis and we analyze how the outcomes of this analysis relate to the observed performance (Chapter 6). And third, we describe the results of the analysis of video observations regarding processes and interactions between actors and how they affect performance (Chapter 7). We conclude the research by combining the results and developing a new conceptual framework to explain variation in operational management performance (Chapter 8). In addition, we reflect on the value of the insights for existing perspectives in the scientific literature. We close with the implications of the research findings for the practice of operational emergency management, exercises and training for more effective emergency management, and the development of resilient and reliable infrastructure (Chapter 9).

Analyzing emergency management performance

Operational emergency management is characterized by a multitude of actors, tasks and objectives. Moreover, emergency management often takes place under physically difficult conditions and time pressure Whether emergency management is effective or not is determined by the extent to which the objectives of the response are achieved. What factors contribute to this achievement?

The literature on emergency management consists of several focus areas including the dealing of actors with large volumes of uncertain information, cooperation between different actors, and decision-making under time pressure and on basis of incomplete information. Attention is also paid to the way in which actors cope with crisis conditions, the role of leadership and management, and collaboration in teams. It is worth mentioning that many insights in the literature on emergency management are based on studies of failures and incidents with a disastrous outcome. Few insights are derived from the analysis of incidents that are managed and resolved quickly.

To explain variation in the effectiveness of multidisciplinary operational emergency management, we use an analytical framework that enables us to explain both good and poor performance. The analytical framework is shown below.



The core of the analytical framework consists of a taxonomy of four emergency management processes. These four processes are 1) developing situational awareness, 2) (emergent) coordination, 3) collective sensemaking, and 4) emergency decision-making. The analytical framework makes a distinction between emergency response in the field (the operational response at the incident location) and joint meetings between actors to coordinate the response, so-called on-scene command team meetings. The four selected processes take place in the field and during joint meetings. Actors gather in the field to share information and develop situational awareness, make sense of the situation, coordinate tasks and decide upon priorities and alternative courses of action. During joint meetings actors share information, develop and verify their shared understanding of the situation, coordinate the emergency response, and decide upon the comprehensive emergency response. The way these processes are executed, both in the field and during meetings, determines the extent to which emergency management objectives are achieved. Emergency management performance consists of results obtained and the extent in which attention is paid to different objectives during the emergency. The framework is the point of departure for the empirical research.

The analytical framework is directly applicable to the Dutch incident command system. The Dutch incident command system includes the GRIP structure (*Gecoördineerde Regionale Incidentbestrijdings Procedure*). According to the GRIP structure, several levels of coordination can be deployed, depending on the size and nature of an incident. Joint meetings consist of on-scene command team meetings (*Commando Plaats Incident (CoPI)*) at the operational level and of a Regional Operational Team (*Regionaal Operationeel Team (ROT)*) at the tactical level. The emergency services, local authorities, and operators of disrupted infrastructure are represented in the coordination structures. Joint meetings are facilitated by a leader of the on-scene command team (*CoPI*) or operational leader (*ROT*) and an information manager.

Virtual reality exercises

Education, training and exercises for emergency management are changing. Virtual technology, primarily from the gaming industry, has found its way to the emergency services. Exercises are increasingly virtual. Virtual reality exercises have often been introduced as serious gaming. However, we argue that virtual reality exercises cannot be characterized as games given the lack of competition, rules and scores. Instead, we argue that it is better to speak of meaningful play. There is a narrative (the scenario), there are players (actors) and there are challenges (tasks and objectives). This means that virtual reality exercises are no games but events that enable participants to use play to prepare for a very serious practice.

Virtual reality exercises provide an opportunity for research. Virtual reality exercises provide better access to researchers than outdoor exercises or actual incidents. They provide opportunities for comparative research as scenarios can be repeated multiple times. Virtual reality exercises allow researchers to observe multidisciplinary emergency response in a (more) systematic way and at close distance. And, virtual reality exercises are particularly suitable for scenarios in which critical infrastructure is involved because virtual environments are capable of putting on complex physical environments.

The use of virtual reality exercises as a research setting adds a methodological component to this study. The question comes up how multidisciplinary emergency management can be studied (best) in virtual reality exercises. We use two methods: communication network analysis and video-observations. We reflect on the usefulness and applicability of these two methods for understanding emergency management performance when discussing the research findings.

The research is conducted during virtual reality exercises at Safety Region *Zeeland*. Safety Region *Zeeland* organizes a continuous series of multidisciplinary, virtual reality exercises with emergency services and regularly invites infrastructure operators. The exercises take place in a standard setting with dedicated exercise staff. We studied twenty exercises in total, including four training scenarios in which the *Westerschelde Tunnel*, highways, various waterways, and the city of Middelburg are key elements. The exercise scenarios involve 1) a major accident involving hazardous materials in the *Westerschelde Tunnel*, 2) an accident that creates a need for large-scale evacuation from the *Westerschelde Tunnel* and involves a threat of criminal violence, 3) an accident with hazardous materials in an urban area where major roads and waterways are blocked, and 4) an accident in a port with many victims and the need to close of a busy shipping route. There are several mono- and multidisciplinary tasks in each scenario. The tasks are mutually dependent - it is often impossible to perform a task in isolation – and require shared situational understanding, multidisciplinary coordination and joint decision-making to be performed successfully.

Study design

The study is designed with the objective to systematically gain practically relevant insights into multidisciplinary operational emergency management. To reach this objective, we use and combine two research methods to create a systematic and rigorous analysis and simultaneously remain open to the subtle and inter-subjective aspects of emergency response. We make use of the paradigm of *mixed methods research.* This paradigm is based on the pragmatic philosophy which aims to provide practical, actionable insights that are warranted by applying scientific methods in a specific setting. The findings of this study should also be seen as such; practical, actionable insights into emergency response that are warranted by the scientific analysis of a series of virtual reality exercises in a Dutch Safety Region.

The analysis starts with an assessment of performance. This is done by assigning scores to the emergency response. Scores are given when a task is being executed and when results are achieved. In addition, the self-assessment of the participating actors during the exercise evaluations is taken into account. The validity of the scores is verified by comparing the performance scores to the outcomes of the self-assessments.

The two research methods applied are communication network analysis and video-ethnography. Network analysis is systematic and provides a structured overview of how the emergency response evolves in the various exercises. Video-ethnography provides a detailed image of how actors deal with tasks, and how results are achieved. Communication network analysis is used to trace two processes from the analytical framework. The development of situational awareness and emergent coordination are traced by analyzing communication in the field. The core idea behind this approach is that situational awareness and coordination are established through communication and communication is thus an indicator of the two processes. Prior to the analyses, we formulate a number of propositions about the expected relationship between communication and performance. The propositions serve as a structure and form the starting point of the empirical investigations.

The video-ethnography consists of the analysis of video observations from selected episodes in the emergency response exercises and the labelling of observations such as actions, statements and conversations or agreements. The video-ethnography is structured by the pairwise analysis of video clips that are selected on basis of the observed performance and outcomes of the communication network analysis.

Outcomes of the empirical research

The empirical research consists of three parts: a description and analysis of emergency management performance, a description and analysis of structural characteristics of communication between emergency response actors, and an analysis of video observations that are used to trace processes that lead to good or poor performance.

The results of the emergency management performance assessment reveal substantial variation between performances. The differences are visible at all levels of the assessment: tasks, individual actors, multidisciplinary subgroups, and the emergency response as a whole. Tasks receive different amounts of attention and are carried out with varying success. Actors and multidisciplinary subgroups perform their tasks in different ways and with different results. And the performance of the emergency response as a whole, the combination of completed tasks and results, varies between exercises. Additionally, the assessment shows that the performance of some actors and on-scene command teams diverges significantly from the average as they achieve exceptionally much or little.

Besides the general outcome of ample variation in performance at all levels of emergency response, there are several more specific outcomes. First, performance with regard to key tasks in emergency response (e.g. firefighting, medical care, and traffic management) is more stable than performance of tasks that are less common (e.g. the handling of fatalities, informing the public about evacuation and the threat of an explosion, and the recovery of disrupted infrastructure). The analysis shows that actors perform their core tasks more steadily than their less common tasks. In line with this result, the variation in the performance of actors is mainly dependent on performance with regard to less common tasks. Second, variation in performance of multidisciplinary tasks is directly related to the number of actors involved in the task. When more actors are involved, there is more variety in performance. Third, the performance of the overall emergency response relies heavily on performance with respect to a small number of core tasks at the beginning of the emergency response. If these core tasks are performed well, others will follow more or less automatically. When these tasks are not executed properly, the consequences cascade towards many other tasks in the response. And finally, it turns out that peaks in performance are more often negative than positive. It is less uncommon for a task to more or less neglected than that an exceptionally good performance is delivered.

The second part of the empirical research describes the structural characteristics of communication and links these characteristics to emergency management performance. The analysis of communication networks reveals differences in how emergency management actors communicate with each other. There is significantly more communication in some cases than in others, and the type of actors that communicate with each other varies. The main findings of the communication network analysis are:

- The *amount* of communication during the response to an emergency is not associated with emergency management performance. The amount of communication is therefore no indicator of effective information sharing and coordination.

- It is not important for actors to be involved in much communication. Having a comparatively large number of contacts with other actors is unrelated to performance.

- If there is a 'golden hour' for operational emergency response to achieve results overall it is not the first hour after an incident has occurred (the hour that is most important for taking care of victims) but the period immediately after the first hour. During this period, most tasks need to be executed and our analysis shows that little communication in this period is associated with high performance.

- The amount of communication in the field varies in accordance with the amount of communication between actors that are not jointly executing a multidisciplinary task. This sort of communication seems to cause distraction. The results indicate that little communication is needed for effective information sharing and co-ordination.

- A central position in the field communication network is important for actors to perform well. It is not about the amount of communication in which an actor is involved but about the position that actors occupy between other actors. This ‘betweenness centrality’ forms a significant indicator of good performance.

These outcomes are a significant result on their own and also form the basis on which video observations are selected for in-depth analysis.

The third part of the empirical outcomes involves the results of the video-ethnographic analysis. The analysis of video clips is guided by the question what actions and interactions between emergency response actors result in good or poor performance. The analysis reveals a large number of influential aspects.

Regarding the development of situational awareness and collective sensemaking during on-scene command team meetings, we observed that meetings are characterized by interactions between actors that draw attention to their goals and interests and team leaders who try to stick to the standard structure of the meetings. The development of situational awareness is greatly influenced by actors who manage to bring their interests to the table and thereby experience little or no resistance from team leaders. We also observed that information managers play a key part in the development of situational awareness and sensemaking because they provide an initial sketch of the emergency situation at the start of a meeting. Actors that inform information managers prior to meetings ensure that their interests are addressed directly at the start of a meeting and usually perform better than actors that do not have contact with the information manager.

Situational awareness and collective sensemaking are developed differently during emergency response in the field. The analysis of video observations demonstrates that situational awareness of individual actors is determined by their ability to gather information. Information is usually unevenly distributed between actors due to differences in access to the incident location and differences in expertise. Some actors possess much information about the incident while others have limited information. The situational awareness of most actors is therefore dependent on the willingness of some actors to share information. Many interactions in the field revolve around the exchange of information between actors with much information and actors who are desperately looking for information to perform their tasks. We observed frequently that "over-questioned" central actors isolate themselves from other actors. This has a positive effect on their own performance but harms the performance of the emergency response as a whole. Short collective meetings in the field help to increase the situational awareness of many actors at once. Such meetings mainly have a positive effect on performance when key actors isolate themselves from other actors beyond the short meetings. The formation of multidisciplinary groups in the field is an effective way to increase situational awareness. However, many of the observed multidisciplinary groups are not functional in the sense that the actors that form the subgroup have no common multidisciplinary task. The presence of many multidisciplinary subgroups does therefore not result in an overall increase of situational awareness.

The analysis of video observations with regard to coordination and decision-making during on-scene command team meetings shows first that waiting and postponing decisions has a delaying effect on the execution of response tasks and thus a negative effect on performance. This is partly because the exercise scenarios involved require immediate interventions and because the uncertainties in the scenarios do not materialized. Taking risks and "macho-like” decision-making are therefore rewarded with good performance scores.

Second, actors with an active or even dominant attitude outperform more reserved actors. This is especially true for actors that do not belong to the traditional emergency services, like representatives of local authorities and infrastructure operators. The interests of these actors are usually not discussed during on-scene command team meetings when they act with restraint. Only a bold attitude helps these actors to promote their interests. Third, team leaders who maintain the 'BOB' structure[14] and manage to stick to the agenda of a meeting increase the performance of the emergency response as a whole. Adherence to the BOB structure and agenda can also lead to dissatisfaction among actors because they feel excluded or claim that their interests have been overlooked.

Finally, the formation of coalitions regarding specific tasks or interests causes better performance with respect to these specific interests because team leaders have

[14] BOB stands for B) situational understanding (*beeldvorming*), O)situational assessment (*oordeelsvorming*) and B) decision-making (*besluitvorming*). The BOB structure is explained in chapter two.

difficulty ignoring an interest or task that is brought to the attention by several actors during on-scene command team meetings.

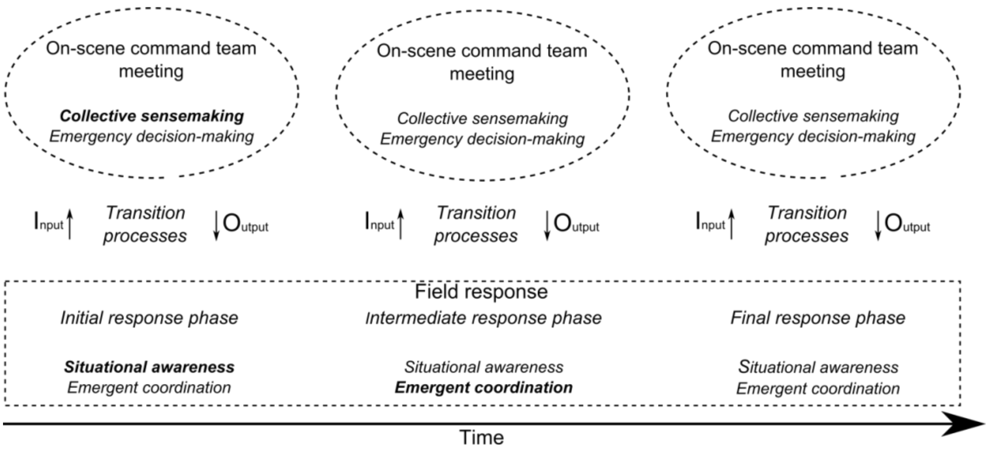
We observed four influential aspects regarding emergent coordination and decision-making in the field. First, the prioritization of tasks is sometimes done on basis of unknown reasons and without an obvious explanation. The observations and post-exercise interviews do not always explain why some actors pay more attention to a task than others. Second, the choice of key actors to act in isolation and not to adopt a central coordinating role helps these actors to perform well but decreases the performance of the emergency response as a whole. When a central actor in an incident scenario isolates himself, the other actors can only perform well when another central actor in the scenario takes the lead. Coordination by non-central actors does not improve performance. Third, there is variety in the level of the response organization at which key tasks are coordinated. The performance of the emergency response as a whole tends to decrease when central tasks are coordinated by multidisciplinary subgroups or individual actors.

The video-ethnography produces several dominant outcomes. Many of the observed actions and interactions have a strong positive or negative effect on performance. Some have a positive effect on the performance of individual actors but a negative effect on the emergency response as a whole. There are two distinct themes in the actions and interactions: control over the structure and agenda of on-scene command team meetings and dealing with the unequal distribution of information and tasks in the field. Regarding the control over the structure and agenda of meetings, actors use different tactics to gain influence on the agenda and team leaders have different ways to keep actors from changing the agenda. The unequal distribution of information and tasks forms the cause of many of the dynamics between actors in the field. On the one hand, actors with a lack of information circle around central actors trying to obtain information. Central actors, on the other hand, face a choice to isolate themselves from others or to pick up a core coordinating role.

The results of the video observations are consistent with the results of the network analysis of communication and explain some of the outcomes. The negative correlation between the amount of communication during the intermediate stages of emergency response and performance is explained by the frequent presence of non-functional interactions. Many communications during emergency response are observed to be non-functional interactions. Interactions that do increase performance require little or no long lasting communication. The degree in which information and tasks are divided unequally between actors affects the way actors interact with each other and the effect of their interactions on performance. The more skewed the distribution is, the more occasions there are for non-functional interactions and the greater the incentive for key actors to isolate themselves. The degree of uneven distribution of information and tasks is therefore an important intervening variable in the relation between communication and performance.

Results: variation explained

The results of the empirical research are translated into a number of insights in how emergency management performance comes about. The first insight involves an enriched view of the processes by which performance comes about (or not). The results of the study confirm the relevance of the four emergency management processes that form the core of the analytical framework and provide a comprehensive overview of detailed (sub)processes that affect performance. These (sub)processes show in detail how situational awareness is developed, how collective sensemaking evolves, and how coordination and emergency decision-making come about. The detailed processes are not just preconditions for performance. We show how they have a specific positive or negative effect on performance, or steer the emergency response towards different objectives. Understanding these detailed processes is crucial for explaining differences in operational emergency management performance. A second insight relates to the processes that we identify during the transitions from emergency response in the field to on-scene command team meetings. The observation that actors that manage to influence a meeting agenda by contacting information managers prior to a meeting shows that the transition between phases is important for understanding differences in performance. A third insight relates to the moments at which processes are important for explaining differences in performance. Temporal differentiation of emergency management processes results in better understanding of emergency management performance. The results of the study provide a basis for the temporal ordering of moments at which the observed processes have an impact on performance. We present a revised conceptual framework for explaining differences in emergency management performance on the basis of these three findings. The revised framework is shown below.



The revised conceptual framework consists of a continuous phase of emergency response in the field, with a parallel series of on-scene command team meetings. The development of situational awareness and emergent coordination of tasks are the most important processes for performance in the field. Collective sensemaking and emergency decision-making are crucial processes for performance during on-scene command team meetings. Transition processes are placed in between emergency response in the field and on-scene command team meeting. Transition processes are mainly of influence for what is discussed in the collective meetings. The moment at which a process affects performance most is indicated with bold text. Performance is mainly influenced by the development of situational awareness in the first phase of emergency response. After the first phase (emergent) coordinating of response tasks becomes more important. Collective sensemaking is crucial in the first on-scene command team meeting. The new conceptual framework is combined with an enriched taxonomy of emergency management processes shown in the table below.

Taxonomy of emergency management processes
<u>Emergency management processes in the field:</u>
Situational awareness
+ Organizing field meetings (++ in combination with self-imposed isolation of key actors)
- Holding on to experts
- Self-imposed isolation from information exchange by key actors
- Circling around key actors
Emergent coordination
+ Coordination in functional subgroups
- Coordination by non-key actors
- Coordination in non-functional subgroups
- Delegating key tasks to subgroups or individual actors
~ Self-imposed isolation from coordination by key actors
<u>Transition processes:</u>
+ Instigating bilateral and multilateral coordination
~ Reporting to the information manager
<u>Emergency management processes in team meetings:</u>
Collective sensemaking
+ Agenda control by team leaders
~ Actor prominence
~ Actor inconspicuousness
~ Disrupting the development of shared understanding of the emergency situation
~ Forming coalitions
Emergency decision-making
- Indecisiveness in response to uncertainty

+ = enhancing performance, - = reducing performance, ~ = adjusting performance

The taxonomy consists of emergency management processes in the field, transition processes, and emergency management processes during on-scene command team meetings. The processes in the field specify how situational awareness is developed and the way in which emergent coordination is achieved or restricted. The emergency response processes during on-scene command team meetings provide an enriched picture of how collective sensemaking enfolds and how emergency decision-making comes about. The transition processes are new and stand alone.

With the revised conceptual framework and enriched taxonomy of processes, we argue that differences in multidisciplinary operational emergency management performance can be explained through a selection of actions and interactions. The actions and interactions in the field revolve around the unequal distribution of information and tasks. The actions and interactions during on-scene command team meetings concerning the setting of the agenda. The processes related to the development of situational awareness are particularly important in the initial phase of emergency response. Coordination in the field is most important during later phases of emergency response. Moreover, the transitions between emergency response in the field and collective meetings are of crucial importance for what is discussed during the meetings.

Arenas as an alternative perspective on emergency management

The combined insights offer a perspective on operational emergency management that is different from the perspective that is commonly encountered in the literature. The actions and interactions that determine on which emergency response is focused, and what interests prevail, provide the impression of an arena. Actors cooperate and struggle in the response arena to reach their objectives and attract attention to their interests. The landscape of the arena is formed by the characteristics of an incident and the challenges that are presented to the actors involved. Understanding and explaining performance in the emergency response arena requires insights from more traditional research on public administration, especially cooperation in networks and agenda setting, more than understanding of the hierarchical command and control structures that are typically used to describe and explain the effectiveness of operational emergency management.

Response arenas form the inner workings that govern the resilience of critical infrastructure. In our introduction, we discuss how the current superficiality of the concept of resilience forms a problem. The outcome of resilience, recovery of a system and ‘bouncing back’ after a disruption, is clear and desirable. The internal mechanism of resilience, the processes by which a system bounces back, generally remain unspecified. The results of this study suggest that resilience of critical infrastructures is the result of interactions between actors, particularly the operators of infrastructures and leaders of the emergency response, that determine how much attention is given to the recovery of disrupted infrastructure. The processes that we identified within the emergency response arena determine performance and effectiveness of emergency management, and form a significant part of the inner workings of resilience.

Practical implications for emergency management and infrastructure resilience

The result of our research is a concrete conceptualization of resilience in relation to critical infrastructures. This concrete conceptualization makes it possible to answer three practical questions. How to be resilient? How to become more resilient? And how to identify resilience?

On basis of our research findings, we provide three answers to the question 'how to be resilient?'.

First, it is necessary to stimulate the processes that we identified to have a positive effect on performance and to repress processes that have a negative impact. Moreover, actors must have knowledge of the processes that shift the focus of emergency response from one response objective to another, and address or initiate these processes when necessary. Team leaders and key actors are only able to steer the response in a desired direction when they have such knowledge at their disposal.

Second, it is necessary to cope with the increasing number of actors on incident locations. The technical expertise required for emergency response in technically complex environments leads to a growth in the number of involved actors. This creates a need for the orchestration of the emergency response and limitation of communications that are not strictly necessary. Technical solutions alone are unlikely to resolve these issues. The communication problems that are encountered around the asymmetric distribution of information and tasks are likely to remain relevant at the operational level, despite the introduction of technical solutions (like platforms for network-centric coordination). A solution will rather lie in making arrangements and developing procedures to avoid information and question overload on the side of central actors. Such agreements and procedures will only have an effect when they are known by all actors, so also by actors that are only sporadically involved in emergency response. Multidisciplinary exercises with actors that are only sporadically involved in emergency response will help to solve this issue.

Third, infrastructure operators increase the likelihood of quick recovery of infrastructures by placing their interests on the emergency response agenda. This can be done by forming coalitions with other actors who seek quick recovery of disrupted infrastructures (such as local authorities) or by ensuring that the recovery of disrupted infrastructure is brought to the attention of key actors in the emergency response, also when these actors isolate themselves from the broader emergency response. Another possibility is to contact information managers before collective meetings start to make sure that infrastructure recovery is part of the operational picture sketched at the start of a meeting.

We also make three recommendations on how to be more resilient. All three recommendations relate to the design and organization of multidisciplinary (virtual) emergency response exercises.

First, we recommend that the evaluation of exercises focuses on emergency management performance in terms of processes *and* outcomes. Evaluations are currently mainly focused on processes, the way in which emergency response is organized and the satisfaction of the actors involved with their actions and those of others. Outcomes and the extent in which results are achieved play a subordinate role. To make actors aware of the different tasks and the extent to which results are achieved, explicit attention must be paid to outcomes.

Second, the orchestrating role of key actors must be emphasized. Nearly all actors in the response to emergencies can end up in a leading role, depending on the specific characteristics of an incident. To initiate and manage cooperation between the growing number of actors on incident sites, leading actors must be capable of orchestrating the response or at least be able to identify potential bottlenecks. Actors might be trained for this competency during exercises by challenging them to send non-crucial actors away from the incident site or to initiate specific subgroups to manage multidisciplinary tasks.

Third, we recommend to increase the familiarity of emergency response actors with the processes that shift the objectives of emergency response. The shifting of objectives often goes unnoticed and actors seem unaware of the processes that make priorities and efforts move from one objective to another. In order to ensure that a deliberate choice is made with respect to the focus of emergency response, it is necessary for actors to recognize the moments at which the focus of the emergency response shifts. Recognizing such moments may be an additional challenge during exercises.

The third practical question we answer is how to identify resilience. The results of this study show what resilience is; the actions and interaction between actors that lead to effective emergency response. We make three recommendations for identifying and analyzing these actions and interactions. These recommendations can be used for future research, for the evaluation of (virtual) exercises, and perhaps even for designing real-time feedback during emergency response operations.

The first recommendation is to move beyond anecdotal evidence and case studies. Case studies offer detailed insight in how emergency response unfolds but focus (too) often on exceptional situations where emergency response has not been successful. To obtain a comprehensive understanding of how effective emergency management comes about, comparative research between positive and negative cases is required. Resilience is not an absolute property and insight in the processes through which resilience comes about can only be obtained by comparing similar incidents with different outcomes.

Second, it is important to develop systematic indicators of resilience. The results of our investigations provide several directions for how this can be done. The position of actors between others and the amount of communication after the first phase of the emergency response prove crucial for understanding emergency management performance. To provide insight, indicators must be supported by theory and proven with data. Development of indicators of resilience can happen in both directions. Systematic analysis of large datasets in search for associations, and then zooming in on specific cases to explain the associations found (the strategy of this study) is one option. Translation of specific insights from case studies to indicators that are systematically tested in large datasets is another possibility. The combination of methods is crucial to get beyond anecdotal support or having to rely on correlations between behavior and outcomes that cannot be substantiated by theory or that have no plausible explanation. Regardless of how resilience indicators are developed, they can then be used for research and for the development of dashboards that allow exercise facilitators and emergency responders to track resilience in real-time.

As a third and final point, we call for the increased use of new techniques such as automated image analysis, automated voice and text analysis, and the use of portable sensors to trace the movements of actors during the response to emergencies. Such techniques help to trace processes and behavior systematically. This is crucial for developing explanations for variation in emergency management performance and the resilience of critical infrastructures.

Samenvatting (Summary in Dutch)

De veerkracht van vitale infrastructuur

Het nationale, economische en ecologische welzijn van geïndustrialiseerde landen is afhankelijk van betrouwbaar functionerende infrastructuur. Om die reden wordt er gesproken over vitale infrastructuur. De betrouwbaarheid van vitale infrastructuur is in het geding door toenemende technologische en organisatorische complexiteit. Integratie van ICT componenten in infrastructuren, afhankelijkheden tussen infrastructuren, en de verdeling van ontwerp, beheer, en onderhoud over vele partijen maken vitale infrastructuren complexer. Het betrouwbaar functioneren van vitale infrastructuur kan enkel in stand worden gehouden wanneer het vermogen om met deze toenemende complexiteit om te gaan gelijke tred houdt. Dit vermogen is niet alleen een kwestie van uitvoerig risico management. Gezien de toenemende complexiteit is de effectiviteit van het anticiperen op risico's en het voorkomen van incidenten beperkt. Om in complexe systemen risico's te beheersen is vooral ook veerkracht nodig, het vermogen om incidenten op te vangen en het systeem zo nodig snel te herstellen.

Veerkracht (*resilience*) is een populair concept. Het vermogen om snel te herstellen na verstoringen is een wenselijke eigenschap die veel toepassingen kent, van organisaties en lokale gemeenschappen tot steden en landen. Wat veerkracht precies inhoud, wat er moet gebeuren om snel te herstellen, is in veel gevallen nog onduidelijk. Deze studie richt zich op de veerkracht van vitale infrastructuur. Door toenemende complexiteit kent de respons op incidenten die infrastructuur verstoren (denk aan grote ongevallen, defecten, of moedwillige verstoringen) steeds meer aspecten. Het aantal doelstellingen neemt toe, het aantal taken dat moet worden uitgevoerd neemt toe, en daardoor neemt ook de noodzaak om de respons te coördineren toe. Effectieve incidentbestrijding is een kwestie van het efficiënt en snel uitvoeren van een veelheid aan taken en het behalen van een veelheid aan doelstellingen. In de context van steeds complexere incidenten en een toenemende druk om infrastructuur te herstellen, stellen wij de vraag wat veerkrachtige infrastructuur is. Wat is er nodig om incidenten snel en efficiënt te bestrijden en vitale infrastructuur te herstellen na verstoringen? Kunnen we vaste patronen of een verzameling van gebeurtenissen en handelingen onderscheiden die aangeven wat veerkrachtige infrastructuur is?

Het doel van dit onderzoek is om het concept veerkracht van vitale infrastructuur nader in te vullen. We doen dit om drie redenen. Ten eerste is het nodig een concrete invulling van de veerkracht van vitale infrastructuur te ontwikkelen om de discussie over veerkracht inhoud te geven en het concept van betekenis te voorzien. Ten tweede is het nodig de effecten van toenemende complexiteit op het vermogen om incidenten te bestrijden en met verstoringen om te gaan beter te begrijpen. Veel van wat we weten over effectieve incidentbestrijding houdt weinig rekening met de snel toenemende technologische complexiteit van infrastructuur en de veelheid aan actoren op een ramplocatie. En ten derde is het nodig te begrijpen welke factoren van invloed zijn op de effectiviteit van incidentbestrijding. Het identificeren en begrijpen van deze factoren is nodig om tot effectievere incidentbestrijding te kunnen komen en de veerkracht van vitale infrastructuur te kunnen vergroten.

In het onderzoek staan twee vragen centraal: (i) hoe coördineren actoren in de operationele incidentbestrijding verschillende taken en doelstellingen, en (ii) hoe bepaalt de manier waarop verschillende taken en doelstellingen worden gecoördineerd de effectiviteit van operationele incidentbestrijding?

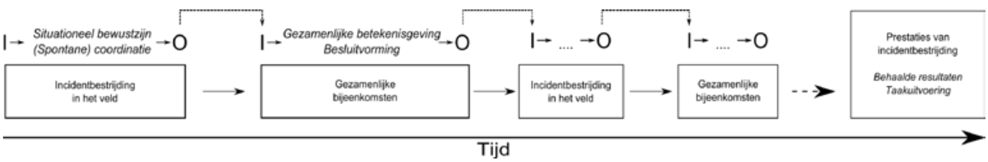
Om bepalende factoren voor effectieve operationele incidentbestrijding te kunnen ontdekken, beschouwen we incidentbestrijding in termen van processen en prestaties (*performance*). We ontwikkelen een analytisch kader waarin verschillende processen en concepten worden samengevoegd waarmee de effectiviteit van incidentbestrijding kan worden verklaard (hoofdstuk 2). Prestaties worden geanalyseerd met nadruk op het uitvoeren van mono- en multidisciplinaire taken en het behalen van resultaten. We bestuderen operationele incidentbestrijding tijdens virtuele oefeningen (hoofdstuk 3). We kiezen voor virtuele oefeningen omdat ze de mogelijkheid bieden processen en interacties tussen actoren systematisch en van dichtbij te observeren. We hanteren een onderzoeksontwerp waarin we een netwerkanalyse van communicatie tussen actoren combineren met een kwalitatieve analyse van video-observaties (hoofdstuk 4). De combinatie stelt ons in staat op systematische wijze een betrouwbaar beeld van operationele incidentbestrijding te ontwikkelen. Het empirisch onderzoek bestaat uit drie delen. Ten eerste beschrijven en analyseren we de geobserveerde prestaties (hoofdstuk 5). Ten tweede beschrijven we de uitkomsten van de netwerkanalyse van communicatie en analyseren we hoe de uitkomsten zich verhouden tot de geobserveerde prestaties (hoofdstuk 6). En ten derde beschrijven we de uitkomsten van de video-observaties en analyseren we hoe de geobserveerde processen en interacties tussen actoren de prestaties beïnvloeden. Hierbij nemen we de eerder verkregen uitkomsten van de netwerkanalyse in acht (hoofdstuk 7). Ter conclusie brengen we de uitkomsten bij elkaar en ontwikkelen we op basis van de gezamenlijke inzichten een nieuw conceptueel kader waarmee verschillen in operationele incidentbestrijding kunnen worden verklaard (hoofdstuk 8). Daarbij reflecteren we op de waarde van de verkregen inzichten voor bestaande perspectieven in de wetenschappelijke literatuur. We sluiten af met de praktische implicaties van de verkregen inzichten voor de praktijk van operationele incidentbestrijding, het voorbereiden en oefenen voor effectievere incidentbestrijding, en de ontwikkeling van veerkrachtige en betrouwbare infrastructuur (hoofdstuk 9).

Een analytisch kader voor prestaties van incidentbestrijding

Operationele incidentbestrijding wordt gekenmerkt door een veelheid aan actoren, taken en doelstellingen. Daarnaast vindt incidentbestrijding vaak plaats onder fysiek lastige omstandigheden en tijdsdruk. Of incidentbestrijding effectief is, wordt bepaald door de mate waarin de verschillende doelstellingen van de incidentbestrijding worden behaald. Welke factoren dragen daaraan bij?

De literatuur over incidentbestrijding is veelzijdig. Centraal staan onder andere het omgaan met grote hoeveelheden en onzekere informatie, de samenwerking tussen verschillende actoren, en het maken van beslissingen onder tijdsdruk en op basis van onzekere informatie. Ook is er aandacht voor de manier waarop actoren omgaan met crisisomstandigheden, de rol van leiderschap en aansturing, en samenwerking in teams. Opvallend is dat in de literatuur over incidentbestrijding veel inzichten zijn gebaseerd op studies over mislukkingen en incidenten met een rampzalige afloop. Veel minder inzichten zijn ontleend aan de analyse van incidenten die snel en succesvol zijn verholpen.

Om verschillende in de effectiviteit van multidisciplinaire operationele incidentbestrijding te kunnen verklaren hanteren we een analytisch kader waarmee zowel goede als mindere prestaties kunnen worden verklaard. Het analytisch kader is hieronder weergeven.



De kern van het analytisch kader wordt gevormd door een taxonomie van vier incidentbestrijdingsprocessen. Deze vier processen zijn 1) het opbouwen van situationeel bewustzijn (*situational awareness*), 2) (spontane) coördinatie (*(emergent) coordination*), 3) gezamenlijke betekenisgeving (*collective sensemaking*), en 4) besluitvorming (*emergency decision-making*). Het analytisch kader maakt onderscheid tussen incidentbestrijding in het veld (de operationele respons op de incidentlocatie) en gezamenlijke bijeenkomsten van actoren waarin de incidentbestrijding wordt gecoördineerd. Die vier processen voltrekken zich in het veld en tijdens centrale bijeenkomsten. Actoren zoeken elkaar op in het veld en delen informatie waarmee ze situationeel bewustzijn creëren en gezamenlijk betekenis aan de situatie geven, ze coördineren taken (spontaan) en beslissen over prioriteiten en mogelijke handelswijzen. Tijdens gezamenlijke bijeenkomsten delen actoren informatie, schetsen en verifiëren ze een gedeeld beeld, wordt de incidentbestrijding gecoördineerd, en worden beslissingen genomen ten aanzien van de incidentbestrijdingsaanpak. De manier waarop dit gebeurt, zowel in het veld als tijdens bijeenkomsten, is bepalend voor de mate waarin de doelstellingen van de incidentbestrijding worden behaald. De prestaties in het analytisch kader bestaan uit behaalde doelstellingen en de mate van aandacht voor verschillende doelstellingen *tijdens* de incidentbestrijding. Het kader vormt het uitgangpunt voor het empirisch onderzoek.

Het analytisch kader sluit nauw aan bij de Nederlandse incidentbestrijdingspraktijk. In Nederland wordt bij grootschalige incidenten gebruik gemaakt van de GRIP structuur (Gecoördineerde Regionale Incidentbestrijdings Procedure). Binnen de GRIP structuur worden, afhankelijk van de omvang van een incident verschillende coördinatiestructuren in het leven geroepen. De gezamenlijke bijeenkomsten bestaan op operationeel niveau uit het Commando Plaats Incident (CoPI) en op tactisch niveau uit het Regionaal Operationeel Team (ROT). In de coördinatiestructuur zijn de hulpdiensten, lokale autoriteiten, en beheerders van getroffen infrastructuur vertegenwoordigd. De bijeenkomsten worden gefaciliteerd door een leider CoPI of operationeel leider (ROT) en een informatiemanager.

Virtuele oefeningen

Opleiden, trainen en oefenen voor incidentbestrijding zijn in verandering. Virtuele technologie, voornamelijk vanuit de gaming industrie, heeft zijn weg gevonden naar de incidentbestrijding. Oefeningen zijn steeds vaker virtueel. Virtuele oefeningen zijn veelal geïntroduceerd als serious gaming. Wij stellen dat er echter geen sprake is van gaming gezien het gebrek aan competitie, spelregels en scores. We stellen dat er wel sprake is van betekenisvol spel. Er is immers een narratief (het scenario), er is sprake van spelers (de actoren) en er zijn uitdagingen. Kortom, virtuele oefeningen zijn geen spelletje maar stellen deelnemers in staat zich door middel van spel voor te bereiden op een uiterst serieuze praktijk.

Virtuele oefeningen bieden een kans voor onderzoek. Virtuele oefeningen zijn toegankelijker voor onderzoekers dan buitenoefeningen en echte incidenten en bieden mogelijkheden voor vergelijkend onderzoek. Daarmee maken virtuele oefeningen het mogelijk multidisciplinaire samenwerking in incidentbestrijding op een (meer) systematische wijze en van dichtbij te observeren. Daarnaast zijn virtuele oefeningen uitermate geschikt voor oefeningen waarin de verstoring van infrastructuur centraal staat omdat virtuele omgevingen geschikt zijn voor het nabootsen van complexe fysieke omgevingen. Het gebruik van virtuele oefeningen voegt een methodologische component toe aan de studie. De vraag rijst immers hoe multidisciplinaire incidentbestrijding in virtuele oefening (het best) kan worden bestudeerd? Wij maken gebruik van twee methoden: analyse van communicatienetwerken en video-observaties. In de discussie blikken we terug op de bruikbaarheid van deze methoden voor het identificeren van veerkracht.

Het onderzoek is uitgevoerd tijdens virtuele oefeningen van Veiligheidsregio Zeeland. Veiligheidsregio Zeeland hanteert een vaste cyclus van virtuele, multidisciplinaire oefeningen met hulpdiensten uit de regio, waarbij regelmatig infrastructuurbeheerders worden uitgenodigd. De oefeningen vinden plaats in een vaste setting met een vaste oefenstaf. In totaal zijn er twintig oefeningen bestudeerd waarbij gebruik is gemaakt van vier oefenscenario's waarin de Westerschelde Tunnel, lokale (snel)wegen, verschillende waterwegen, en de stad Middelburg centraal staan. De oefenscenario's betreffen 1) een groot ongeval met gevaarlijke stoffen in de Westerschelde Tunnel, 2) een ongeval met noodzaak tot grootschalige evacuatie vanuit de Westerschelde Tunnel en een dreiging van crimineel geweld, 3) een ongeval met gevaarlijke stoffen in een stedelijke omgeving waarbij belangrijke wegen en vaarroutes worden geblokkeerd, en 4) een ongeval in een haven met veel slachtoffers waardoor een drukke vaarroute wordt geblokkeerd. In elk scenario is sprake van meerdere monodisciplinaire en multidisciplinaire taken. De taken zijn onderling afhankelijk – het is vaak onmogelijk om taken los van elkaar uit te voeren – waardoor gedeelde beeldvorming, multidisciplinaire afstemming, en gezamenlijke besluitvorming vereist zijn voor succesvolle incidentbestrijding.

Ontwerp van het onderzoek

Het onderzoek is ontworpen met als doel op systematische wijze relevante inzichten in operationele, multidisciplinaire incidentbestrijding te verkrijgen. We maken daartoe gebruik van twee onderzoeksmethoden die we combineren om een systematische en zuivere analyse te maken en tegelijk ontvankelijk te zijn voor de subtiele en intersubjectieve aspecten van incidentbestrijding. We maken daarmee gebruik van een *mixed methods research* paradigma. Deze onderzoekswijze is gebaseerd op de pragmatische filosofie die erop is gericht praktisch bruikbare inzichten te verschaffen die met wetenschappelijke methoden zijn gegrond (*warranted*) in een specifieke onderzoekssetting. Zo moeten de uitkomsten van dit onderzoek ook worden gezien; praktisch bruikbare inzichten over processen van incidentbestrijding die door wetenschappelijke analyse van een serie virtuele oefeningen in Veiligheidsregio Zeeland zijn gegrond.

De analyse start met het beoordelen van prestaties. Dit wordt gedaan door scores toe te kennen aan de incidentbestrijding. Scores worden gegeven wanneer een taak wordt uitgevoerd en wanneer resultaat wordt geboekt ten aanzien van een taak. Daarnaast wordt de zelfbeoordeling van de deelnemers tijdens de evaluaties na afloop van de oefeningen geanalyseerd. Door de toegekende scores te vergelijken met de zelfbeoordeling wordt de validiteit van de scores gecontroleerd en nagegaan of er discrepantie bestaat tussen de gerealiseerde resultaten en de tevredenheid van actoren met de incidentbestrijding.

De twee toegepaste onderzoeksmethoden zijn netwerkanalyse van communicatie en video-etnografie. Netwerkanalyse is systematisch en zorgt voor een gestructureerd overzicht van de manier waarop de incidentbestrijding zich voltrekt in de verschillende oefeningen. Video-etnografie geeft een gedetailleerd beeld van de manier waarop actoren handelen, met welke taken ze zich bezig houden, en hoe resultaten tot stand komen. De netwerkanalyse van communicatie is gebruikt om twee processen uit het analytisch kader te traceren. Het ontwikkelen van situationeel bewustzijn en spontane coördinatie worden zichtbaar gemaakt door analyse van communicatie in het veld. De kerngedachte achter deze benadering is dat situationeel bewustzijn en coördinatie tot stand komen door middel van communicatie die daarmee een indicator vormt voor beide processen. Voorafgaand aan de analyse formuleren we een aantal proposities over de verwachte relatie tussen communicatie en prestaties. De proposities dienen als uitgangspunt en geven structuur aan de empirische analyse.

De video-etnografie bestaat uit de analyse van videobeelden door transcriptie van videofragmenten en het labellen van specifieke observaties zoals gedragingen, uitspraken of afspraken. De video-etnografie is gestructureerd door videofragmenten, die zijn geselecteerd op basis van geobserveerde prestaties en de uitkomsten en de netwerkanalyse, paarsgewijs te analyseren.

Uitkomsten van het empirisch onderzoek

Het empirisch onderzoek bestaat uit drie delen: een beschrijving en analyse van prestaties, een beschrijving en analyse van structurele kenmerken van communicatie, en een analyse van videofragmenten waarmee de processen die tot goede of slechte prestaties leiden worden getraceerd.

De analyse van prestaties in de incidentbestrijding in de oefeningen (hoofdstuk 5) laat substantiële verschillen zien. Op alle analyse niveaus is sprake van prestatieverschillen: specifieke taken, individuele actoren, multidisciplinaire groepen, en de incidentbestrijding als geheel. Taken krijgen een verschillende hoeveelheid aandacht en worden met wisselend succes uitgevoerd. Actoren en multidisciplinaire groepen voeren hun taken op verschillende manieren en met divers resultaat uit. En de incidentbestrijding als geheel, het totaal van afgehandelde taken en behaalde resultaten, verschilt per oefening. Daarnaast vertonen sommige actoren en incidentbestrijdingsteams prestaties die sterk afwijken van het gemiddelde door uitzonderlijk veel of juist weinig resultaten te behalen.

Naast de algemene uitkomst van veel variatie op alle niveaus heeft de analyse van prestaties een aantal meer specifieke uitkomsten. Ten eerste zijn de prestaties met betrekking tot kerntaken in de incidentbestrijding (bijvoorbeeld brandbestrijding, spoedeisende medische hulpverlening, en handhaving van mobiliteit) stabieler dan prestaties ten aanzien van taken die minder gebruikelijk zijn (bijvoorbeeld de afhandeling van dodelijke slachtoffers, informeren van het publiek over evacuatie en explosiegevaar, en het herstel van verstoorde infrastructuur). Uit de analyse blijkt dat actoren hun kerntaken stabieler uitvoeren dan hun minder gebruikelijke taken. In lijn met deze uitkomst is de variatie in de prestaties van actoren voornamelijk afhankelijk van prestaties ten aanzien van minder gebruikelijke taken. Ten tweede blijkt de variatie in prestaties van multidisciplinaire taken direct evenredig te variëren met het aantal bij de taak betrokken actoren. Hoe meer actoren betrokken zijn, hoe meer variatie. Ten derde blijkt dat de prestaties van de incidentbestrijding als geheel sterk afhangen van de prestatie ten aanzien van een klein aantal kerntaken aan het begin van de incidentbestrijding. Als deze kerntaken goed worden uitgevoerd, volgt de rest als het ware vanzelf. Worden deze kerntaken niet, of niet goed uitgevoerd dan ondervinden andere taken daar de gevolgen van. Als laatste blijkt dat uitschieters in prestaties vaker negatief dan positief zijn. Het komt vaker voor dat een taak min of meer wordt verwaarloosd dan dat er een uitzonderlijke goede prestatie wordt geleverd.

Het tweede deel van het empirisch onderzoek koppelt structurele kenmerken van communicatie aan de effectiviteit van incidentbestrijding. De analyse van communicatienetwerken brengt grote verschillen aan het ligt in de manier waarop actoren tijdens incidentbestrijding met elkaar communiceren. In sommige gevallen wordt veel meer gecommuniceerd dan in andere, en in het ene geval spreken heel andere actoren met elkaar dan in het andere geval. De belangrijkste uitkomsten van de communicatienetwerkanalyse zijn:

- De hoeveelheid communicatie tijdens incidentbestrijding houdt geen verband met de geleverde prestaties. De hoeveelheid communicatie vormt daarmee geen indicator van effectieve informatie-uitwisseling en coördinatie.
- Het is voor actoren niet van belang bij veel communicatie betrokken te zijn. Het hebben van relatief veel contacten met andere actoren houdt geen verband met goede prestaties.
- Als er sprake is van een 'gouden uur' voor het totaal aan prestaties in operationele incidentbestrijding dan is dit niet het eerste uur nadat een incident heeft plaatsgevonden (de periode die het meest relevant is voor het helpen van slachtoffers) maar de periode direct na het eerste uur. In de periode direct na het eerste uur moeten de meeste taken worden uitgevoerd en blijkt het zaak zo weinig mogelijk te hoeven communiceren. De hoeveelheid communicatie in deze periode staat in omgekeerd evenredig verband met prestaties van incidentbestrijding.
- De hoeveelheid communicatie tijdens incidentbestrijding in het veld varieert met name door de hoeveelheid communicatie tussen actoren die niet gezamenlijk een taak uitvoeren. Deze communicatie lijkt voornamelijk voor afleiding te zorgen. Voor effectieve informatie-uitwisseling en coördinatie blijkt relatief weinig communicatie nodig te zijn.
- Het bekleden van een centrale positie in het communicatie netwerk tijdens incidentbestrijding is belangrijk voor actoren om goed te presteren. Het gaat niet om de hoeveelheid communicatie waarbij een actor betrokken is maar de positie in het netwerk tussen andere actoren. Deze positie vormt een significante indicator van goede prestaties.

Deze uitkomsten zijn een belangrijk resultaat op zich en vormen tevens de structuur op basis waarvan videofragmenten zijn geselecteerd voor meer diepgaande analyse.

Het derde deel van het empirisch onderzoek betreft de uitkomsten van een video-etnografische analyse. In de analyse van videofragmenten staat de vraag centraal welke handelingen en interacties tussen actoren in de incidentbestrijding tot goede of juist slechte prestaties leiden. De analyse brengt een groot aantal invloedrijke aspecten aan het licht.

Ten aanzien van de ontwikkeling van situationeel bewustzijn en gezamenlijke betekenisgeving tijdens gezamenlijke bijeenkomsten blijkt het volgende. De bijeenkomsten worden gekenmerkt door interacties tussen actoren die aandacht vragen voor hun doelstellingen en belangen en teamleiders die de vaste structuur van de bijeenkomsten proberen aan te houden. Het ontwikkelde situationeel bewustzijn wordt sterk beïnvloed door actoren die erin slagen hun belangen naar voren te brengen en daarbij geen of weinig weerstand ondervinden van teamleiders. Informatiemanagers spelen hierbij een centrale rol omdat zij bij aanvang van een bijeenkomst de eerste situatieschets geven. Actoren die voorafgaand aan een bijeenkomst contact hebben met de informatiemanager zorgen ervoor dat hun belangen direct bij aanvang van een bijeenkomst aan bod komen en presteren uiteindelijk doorgaans beter dan actoren die niet communiceren met informatiemanagers.

Situationeel bewustzijn en gezamenlijke betekenisgeving komen op andere wijze tot stand tijdens incidentbestrijding in het veld. De analyse van videofragmenten laat zien dat het situationeel bewustzijn van individuele actoren wordt bepaald door het vermogen om informatie te verzamelen. Informatie is doorgaans ongelijk verdeeld over actoren als gevolg van verschillen in toegang tot de incidentlocatie en verschillen in expertise. Enkele actoren beschikken over veel informatie terwijl veel actoren over beperkte informatie beschikken. Het situationeel bewustzijn van de meeste actoren is daarom afhankelijk van de bereidheid van enkele actoren om informatie te delen. Veel interacties tussen actoren in het veld draaien om de uitwisseling van informatie tussen actoren met veel informatie en actoren die naarstig op zoek zijn naar informatie om hun taken uit te kunnen voeren. Het komt regelmatig voor dat de 'overbevraagde', centrale actoren zich afzonderen van de andere actoren. Dit komt hun eigen prestaties ten goede maar schaadt de prestaties van de incidentbestrijding als geheel. Een korte bijeenkomst in het veld – een zogenaamd motorkapoverleg – helpt om het situationeel bewustzijn van veel actoren in één keer te vergroten. Dit heeft vooral een positieve uitwerking op prestaties wanneer centrale actoren zich buiten dit veldoverleg om van andere actoren afzonderen. De vorming van multidisciplinaire groepen in het veld blijkt een effectieve manier om situationeel bewustzijn te vergroten. Veel van de geobserveerde multidisciplinaire groepen zijn echter niet functioneel in de zin dat de actoren in de groep geen gezamenlijke multidisciplinaire taak hebben. De aanwezigheid van (veel) multidisciplinaire groepen vormt daarom geen garantie voor een toename van situationeel bewustzijn.

Uit de analyse van videofragmenten met betrekking tot coördinatie en besluitvorming tijdens gezamenlijke bijeenkomsten blijkt het volgende. Ten eerste hebben een afwachtende houding en het uitstellen van besluiten een vertragend effect op de uitvoering van incidentbestrijdingstaken en daarmee een negatieve invloed op prestaties. Dit komt mede doordat de bestudeerde scenario's direct ingrijpen vereisen en de onzekerheden die vanuit de scenario's presenteren zich uiteindelijk niet manifesteren. Het nemen van risico's en 'macho'-achtige besluitvorming worden daardoor beloond met goede prestaties.

Ten tweede blijkt dat actoren met een actieve en soms dominante houding beter presteren dan meer terughoudende actoren. Dit geldt vooral voor actoren die doorgaans niet tot de kernactoren van operationele incidentbestrijding worden gerekend, zoals vertegenwoordigers van lokale gemeenten en de beheerders van infrastructuur. Wanneer zij zich terughoudend opstellen worden hun belangen doorgaans niet behandeld tijdens gezamenlijke bijeenkomsten.

Ten derde komt naar voren dat teamleiders die vasthouden aan de 'BOB'-structuur[15] en de agenda van een bijeenkomst voor betere prestaties van de incidentbestrijding in het geheel zorgen. Het vasthouden aan de BOB-structuur en agenda kan wel leiden tot onvrede bij actoren omdat zij zich niet gehoord voelen. Als laatste blijkt dat het vormen van coalities ten aanzien van specifieke belangen zorgt voor betere prestaties ten aanzien van die belangen omdat teamleiders tijdens gezamenlijke bijeenkomsten moeite hebben een belang of doel te negeren dat door meerdere actoren onder de aandacht wordt gebracht.

Ten aanzien van spontane coördinatie en besluitvorming in het veld vallen vier aspecten op. Ten eerste gebeurt de priorisering van taken deels op basis van onbekende redenen en zonder voor de hand liggende verklaring. Uit de videofragmenten en interviews na afloop van de oefeningen kan niet altijd worden opgemaakt waarom de ene actor meer aandacht aan een taak besteed dan een andere. Ten tweede blijkt opnieuw dat de keuze van centrale actoren om in afzondering op te treden en geen centrale coördinerende rol op te nemen deze actoren helpt om voor zichzelf resultaat te boeken maar schade toebrengt aan de prestaties van de incidentbestrijding als geheel. Wanneer de centrale actor in een incidentscenario zich terugtrekt kunnen de andere actoren alleen goed presteren wanneer een andere centrale actor in het scenario het voortouw neemt. Ten derde blijkt dat er variëteit is wat betreft het niveau van de incidentbestrijdingsorganisatie waarop belangrijke taken worden gecoördineerd. Wanneer centrale taken in de incidentbestrijding door multidisciplinaire groepen of individuele actoren worden gecoördineerd of uitgevoerd dan dalen de prestaties van incidentbestrijding doorgaans als geheel.

Uit het video-etnografisch onderzoek komen een aantal dominante beelden naar voren. Veel van de terugkerende handelingen en interacties hebben een uitgesproken positief of negatief effect op prestaties. Enkele hebben een positief effect voor individuele

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[15] BOB staat voor beeldvorming, oordeelsvorming en besluitvorming. De BOB-structuur wordt toegelicht in hoofdstuk 2.

actoren maar een negatief gevolg voor de incidentbestrijding als geheel. In de handelingen en interacties zijn twee centrale thema's te onderscheiden: controle over de structuur en agenda van gezamenlijke bijeenkomsten en de omgang met de ongelijke verdeling van informatie en taken in het veld. Wat betreft de controle over de structuur en agenda van bijeenkomsten hebben actoren verschillende tactieken om belangen op de agenda te krijgen en hebben teamleiders verschillende manieren om belangen terug te dringen. De ongelijke verdeling van informatie en taken vormt de oorzaak van veel van de dynamiek tussen actoren in het veld. Actoren met een gebrek aan informatie cirkelen om centrale actoren heen op zoek naar informatie. Centrale actoren zien zich op hun beurt voor de keuze gesteld zich af te zonderen of een centrale coördinerende rol op te pakken.

De uitkomsten van de video-observaties sluiten aan bij de uitkomsten van de analyse van communicatienetwerken en verklaren deze deels. De negatieve relatie tussen de hoeveelheid communicatie en prestaties na het eerste uur van de incidentbestrijding wordt verklaard door de aanwezigheid van non-functionele interacties. Veel communicatie tijdens de incidentbestrijding komt voort uit non-functionele interacties die doorgaans samen gaan met mindere prestaties in de bestudeerde oefeningen. Interacties die prestaties verhogen vergen weinig, of geen langdurige communicatie. De mate waarin informatie en taken ongelijk zijn verdeeld over actoren is van invloed op de manier waarop actoren met elkaar communiceren en het effect dat dit heeft op prestaties. Hoe schever deze verdeling is, hoe meer mogelijkheden er zijn voor non-functionele interacties en hoe sterker de prikkel voor centrale actoren om zich af te zonderen. De mate van ongelijke verdeling van informatie en taken is daarmee een belangrijke interveniëren variabele voor de relatie tussen communicatie en prestaties.

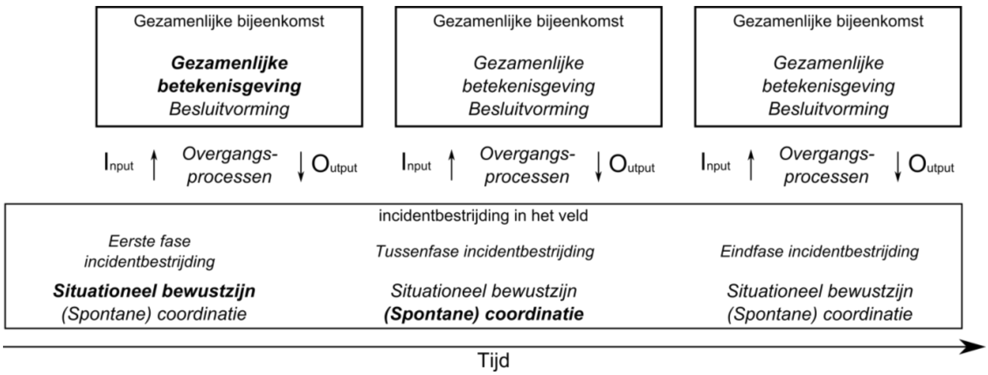
Resultaten van het onderzoek: verschillen verklaard

De uitkomsten van het empirisch onderzoek laten zich vertalen in een aantal inzichten in hoe prestaties tijdens operationele incidentbestrijding tot stand komen. Het eerste inzicht bestaat uit een verrijkt beeld van de processen waardoor prestaties tot stand komen (of juist worden belemmerd). De uitkomsten van het onderzoek bevestigen de relevantie van de vier incidentbestrijdingsprocessen die samen de kern van het analytisch kader vormen en bieden een uitvoerig overzicht van gedetailleerde (sub)processen die aan prestaties voorafgaan. Deze (sub)processen laten in detail zien hoe het ontwikkelen van situationeel bewustzijn, gezamenlijke betekenisgeving, (spontane) coördinatie, en besluitvorming in hun werk gaan. De gedetailleerde processen zijn niet enkel randvoorwaardelijk voor prestaties maar we laten zien dat ze een specifiek positief, negatief of sturend effect op prestaties hebben. De gedetailleerde processen zijn daarmee cruciaal voor het verklaren van verschillen in prestaties in operationele incidentbestrijding.

Een tweede inzicht is gebaseerd op de processen die we identificeren tijdens de overgang van incidentbestrijding in het veld naar gezamenlijke bijeenkomsten. Met name de uitkomst dat actoren die voorafgaand aan bijeenkomsten de agenda beïnvloeden beter presteren dan anderen laat zien dat de overgang tussen de twee fasen belangrijk is om verschillen in prestaties te begrijpen.

Een derde inzicht draait om de momenten waarop processen belangrijk zijn voor het verklaren van verschillen in prestaties. Op basis van de uitkomsten van het onderzoek kan een temporele ordening worden aangebracht in de momenten waarop processen van invloed zijn op prestaties. Ons analytisch kader hield geen rekening met wanneer een proces invloed heeft op prestaties en ging ervan uit dat het effect gelijk blijft gedurende de incidentbestrijding. Om prestaties van incidentbestrijding beter te begrijpen is een temporeel gedifferentieerd, of dynamisch model nodig.

Op basis van deze drie inzichten presenteren we een verbeterd conceptueel kader voor het verklaren van prestatieverschillen. Het nieuwe kader is hieronder weergegeven.



Het nieuwe conceptuele kader bestaat uit een doorlopende fase van incidentbestrijding in het veld met een parallelle serie van gezamenlijke bijeenkomsten. In het veld zijn de ontwikkeling van situationeel bewustzijn en de (spontane) coördinatie van taken het meest belangrijk voor goede incidentbestrijdingsprestaties. Tijdens gezamenlijke bijeenkomsten draait het vooral om gezamenlijke betekenisgeving en besluitvorming. Tussen de incidentbestrijding in het veld en de gezamenlijke bijeenkomsten bevinden zich overgangsprocessen die bepalend zijn voor wat er in de gezamenlijke bijeenkomsten besproken wordt. Het moment waarop een proces voornamelijk van invloed is op incidentbestrijdingsprestaties is aangegeven door de tekst dik te drukken. In de eerste fase van de incidentbestrijding in het veld is vooral het ontwikkelen van situationeel bewustzijn van belang. Na de eerste fase wordt (spontane) coördinatie van incidentbestrijdingstaken belangrijker. Tijdens de eerste gezamenlijke bijeenkomst is het proces van gezamenlijke betekenisgeving cruciaal.

Het nieuwe conceptuele kader gaat hand in hand met een uitgebreidere taxonomie van processen tijdens incidentbestrijding. De taxonomie bestaat uit processen in het veld, overgangsprocessen, en processen tijdens gezamenlijke bijeenkomsten. De processen in het veld specificeren de manier waarop situationeel bewustzijn wordt ontwikkeld en de manier waarop (spontane) coördinatie tot stand komt of wordt belemmerd. De incidentbestrijdingsprocessen tijdens gezamenlijke bijeenkomsten verrijken het beeld van hoe gezamenlijk betekenis wordt gegeven en hoe besluitvorming wordt beïnvloed. De overgangsprocessen zijn nieuw en staan op zichzelf. Onderstaande tabel biedt een overzicht van de processen.

Taxonomie van incidentbestrijdingsprocessen

Incidentbestrijdingsprocessen in het veld:
Situationeel bewustzijn:
+ Organiseren van veldbijeenkomsten (motorkapoverleg) (++ in combinatie met afzondering van centrale actoren)
- Claimen van experts door een enkele actor
- Afzondering van informatie-uitwisseling door centrale actoren
- 'Cirkelen' rond centrale actoren
(Spontane) coördinatie:
+ Coördinatie in functionele multidisciplinaire groepen
- Coördinatie in niet-functionele multidisciplinaire groepen
- Coördinatie door niet-centrale actoren
- Delegeren van belangrijke multidisciplinaire taken naar groepen of individuele actoren
~ Afzondering van coördinatie door centrale actoren
Overgangsprocessen:
+ Aanjagen van bilaterale en multilaterale groepen rondom multidisciplinaire taken
~ Informeren van de informatiemanager
Incidentbestrijdingsprocessen in gezamenlijke bijeenkomsten:
Gezamenlijke betekenisgeving:
+ Vasthouden aan de agenda en de BOB structuur door teamleiders
~ Uitgesprokenheid van actoren
~ Terughoudendheid van actoren
~ Onderbreking van het gezamenlijke proces van betekenisgeving
~ Vorming van coalities
Besluitvorming:
- Terughoudendheid en een afwachtende houding in geval van onzekerheid

+ = bevordert prestaties, - = vermindert prestaties, ~ = verandert prestaties

Met het vernieuwde conceptuele kader en de taxonomie van processen stellen we dat verschillen in prestaties van operationele incidentbestrijding worden verklaard door een verzameling handelingen en interacties die in het veld vooral om de ongelijke verdeling van informatie draaien en tijdens gezamenlijke bijeenkomsten voornamelijk over het bepalen van de agenda. Daarbij zijn processen met betrekking tot de ontwikkeling van situationeel bewustzijn vooral van belang in de eerste fase van een incident en speelt coördinatie in het veld met name een rol tijdens latere fasen van de incidentbestrijding. Bovendien zijn de transities tussen incidentbestrijding in het veld en gezamenlijke bijeenkomsten van cruciaal belang voor wat er tijdens de bijeenkomsten wordt besproken.

De arena als alternatief perspectief op incidentbestrijding

De gezamenlijke inzichten bieden een ander perspectief op operationele incidentbestrijding dan het perspectief dat doorgaans wordt gehanteerd in de literatuur. De handelingen en de interacties die bepalen op welke doelen de incidentbestrijding zich focust en welke belangen voorrang krijgen schetsen het beeld van een arena. In de arena werken actoren afwisselend samen en voeren ze strijd om voorrang voor doelen en belangen. Het landschap van de arena wordt gevormd door de specifieke kenmerken van een incident en de uitdagingen die daaruit voortkomen voor de betrokken actoren. Het begrijpen en verklaren van prestaties in deze arena vergt het gebruik van inzichten uit de traditionele bestuurskunde en samenwerking in netwerken, meer dan begrip van de hiërarchisch bevel- en coördinatiestructuren die doorgaans worden gebruikt om de effectiviteit van operationele incidentbestrijding te beschrijven en verklaren.

De arena's van incidentbestrijding vormen het inwendige mechanisme dat we bepalend achten voor de veerkracht van vitale infrastructuur. In de inleiding van het onderzoek stellen we dat de huidige oppervlakkigheid van het begrip veerkracht een probleem vormt. Het resultaat van veerkracht is duidelijk en gewenst; een systeem herstelt en 'veert terug' na een verstoring. Maar het inwendige mechanisme, de processen waardoor een systeem terugveert, blijven in de regel onbenoemd. De resultaten van dit onderzoek duiden erop dat veerkracht van vitale infrastructuur het resultaat is van interacties tussen actoren, in het bijzonder de beheerders van infrastructuur en leidende actoren in de incidentbestrijding, waarin wordt bepaald hoeveel aandacht er uitgaat naar het herstel van verstoorde infrastructuur. De processen binnen de incidentbestrijdingsarena bepalen prestaties en de effectiviteit van incidentbestrijding en vormen daarmee een belangrijk deel van het inwendige mechanisme van veerkracht.

Implicaties en aanbevelingen voor effectieve incidentbestrijding en veerkrachtige infrastructuur

Met de resultaten van het onderzoek geven we een concrete invulling van het begrip veerkracht in vitale infrastructuur. Deze concrete invulling maakt het mogelijk drie praktische vragen te beantwoorden. Wat moet er gebeuren om veerkrachtig te zijn? Wat kan er gedaan worden om veerkrachtiger te worden? En hoe kunnen we veerkracht herkennen?

Op de vraag wat er gedaan moet worden om veerkrachtig te zijn geven we op basis van de onderzoeksuitkomsten drie antwoorden.

Ten eerste is het zaak de in dit onderzoek geïdentificeerde processen met een positieve invloed op incidentbestrijdingsprestaties te stimuleren en de processen met een negatieve invloed tegen te gaan. Daar komt bij dat bij incidentbestrijding betrokken actoren kennis moeten hebben van processen waardoor de aandacht wordt verlegd van de ene incidentbestrijdingsdoelstelling naar een andere. Alleen met kennis van deze processen zijn teamleiders en centrale actoren in staat de incidentbestrijding in een gewenste richting te sturen.

Ten tweede is het nodig om te gaan met het toenemend aantal actoren op incidentlocaties. De technische expertise die nodig is voor incidentbestrijding in een technisch complexe omgeving zorgt voor een groei van het aantal aanwezige partijen. Dit creëert een noodzaak voor het regisseren van de incidentbestrijding en het beperken van communicatie wanneer dit niet noodzakelijk is. Dat technische middelen alleen hiervoor een uitkomst bieden is onwaarschijnlijk. De communicatieproblemen die ontstaan rondom de asymmetrische verdeling van informatie en taken blijven op operationeel niveau ook met de komst van technische middelen – zoals platforms voor netwerk centrisch optreden – een belangrijke rol spelen. Een uitkomst ligt eerder in de ontwikkeling van procedures en het maken van afspraken om het overbevragen en overbelasten van centrale actoren te voorkomen. Het is uiteraard cruciaal dat deze afspraken en procedures bij iedereen bekend zijn, dus ook bij actoren die slechts sporadisch als gevolg van specifieke incidentkenmerken bij incidentbestrijding betrokken zijn. Multidisciplinair oefenen met actoren die slechts sporadisch bij incidentbestrijding zijn betrokken, kan hier een bijdrage aan leveren.

Ten derde vergroten infrastructuurbeheerders de kans op snel herstel van infrastructuur door hun belangen op de incidentbestrijdingsagenda te plaatsen. Dit kan onder andere door coalities aan te gaan met andere actoren die snel herstel van infrastructuren beogen (zoals lokale autoriteiten) en te zorgen dat het herstel van verstoorde infrastructuur onder de aandacht wordt gebracht van centrale actoren in de incidentbestrijding, ook wanneer deze actoren zich vanwege hun vele taken afzonderen van de bredere incidentbestrijding.

Voor de vraag wat er gedaan kan worden om veerkrachtiger te worden doen we ook drie aanbevelingen. Alle aanbevelingen hebben betrekking op het ontwerp en de uitvoering van multidisciplinaire (virtuele) incidentbestrijdingsoefeningen.

Ten eerste bevelen we aan om in de evaluatie van oefeningen aandacht te besteden een zowel processen als uitkomsten. In de huidige praktijk wordt voornamelijk aandacht besteed aan processen, de manier waarop de incidentbestrijding is uitgevoerd en de tevredenheid van de betrokken actoren met hun optreden en dat van anderen. Uitkomsten en de mate waarin resultaten worden behaald spelen een ondergeschikte rol. Om actoren bewust te maken van de verschillende taken en de mate waarin resultaat wordt geboekt ten aanzien van de verschillende taken zou het goed zijn expliciete aandacht te besteden aan uitkomsten.

Ten tweede kan meer nadruk gelegd worden op de orkestrerende rol van leidende actoren. Afhankelijk van de specifieke kenmerken van een incident kunnen bijna alle actoren in de incidentbestrijding een leidende rol krijgen. Om de samenwerking tussen een steeds groter aantal actoren goed te laten verlopen, moeten leidende actoren in staat zijn andere actoren aan te sturen of in ieder geval in staat zijn mogelijke knelpunten te herkennen. Actoren kunnen in oefeningen als uitdaging krijgen niet cruciale actoren weg van de incidentlocatie te sturen of specifieke groepen samen te stellen rondom multidisciplinaire taken.

Ten derde bevelen we aan om de bekendheid van actoren met de in dit onderzoek geïdentificeerde processen die de doelstellingen van incidentbestrijding verleggen te vergroten. Het verschuiven van doelstellingen gaat dikwijls ongemerkt en actoren lijken zich niet bewust van de manier waarop de focus van de incidentbestrijding zich verplaatst. Om ervoor te zorgen dat er een bewuste keuze wordt gemaakt ten aanzien van de focus van incidentbestrijding is het noodzakelijk dat actoren de momenten herkennen waarop de focus van de incidentbestrijding wordt verlegd. Dit kan een bijkomende uitdaging tijdens oefeningen zijn.

De derde praktische vraag is hoe veerkracht herkend kan worden. De uitkomsten van het onderzoek laten zien wat veerkracht is; de handeling en interacties tussen actoren die leiden tot effectieve incidentbestrijding. We doen drie aanbevelingen om deze handelingen en interacties te identificeren en analyseren. Dit is bruikbaar voor toekomstig onderzoek, voor de evaluatie van (virtuele) oefeningen en mogelijk zelfs voor real-time feedback tijdens incidentbestrijding.

De eerste aanbeveling is om verder te gaan dan anekdotische onderbouwing en casestudies. Casestudies bieden gedetailleerd inzicht in hoe incidentbestrijding zich voltrekt maar focussen (te) vaak op uitzonderlijke situaties waarin de incidentbestrijding niet goed is verlopen. Om een volledig inzicht te krijgen in de manier waarop effectieve incidentbestrijding tot stand komt is vergelijkend onderzoek nodig tussen positieve en negatieve gevallen. Veerkracht is geen absoluut gegeven en alleen door de bestrijding van soortgelijke incidenten te vergelijken, kunnen de processen waardoor effectieve incidentbestrijding (en daarmee veerkracht) tot stand komt, worden geïdentificeerd.

Ten tweede is het belangrijk systematische indicatoren van veerkracht te ontwikkelen. De uitkomsten van het onderzoek geven daartoe enkele aanwijzingen. De positie van actoren tussen anderen in en de hoeveelheid communicatie na de eerste fase van de incidentbestrijding blijken cruciaal om prestaties in incidentbestrijding te begrijpen. Om inzicht te geven moeten indicatoren zijn onderbouwd met theorie en bewezen met data. Ontwikkeling van indicatoren van veerkracht kan in beide richtingen. Systematische analyse van grote hoeveelheden data op zoek naar verbanden, en daarna inzoomen op specifieke gevallen om de aangetroffen verbanden te verklaren (de strategie van dit onderzoek) is een mogelijkheid. Het vertalen van specifieke inzichten uit casestudies naar indicatoren die vervolgens systematisch getest worden in grootschalig vergelijkend onderzoek is een andere mogelijkheid. De combinatie van methoden is cruciaal om voorbij anekdotische onderbouwing te komen maar niet te hoeven vertrouwen op correlaties tussen gedrag en uitkomsten die niet met theorie kunnen worden onderbouwd of geen plausibele verklaring kennen. Ongeacht de manier waarop indicatoren van veerkracht zijn ontwikkeld, kunnen ze vervolgens worden gebruikt voor onderzoek en voor de ontwikkeling van dashboards om veerkracht in *real-time* te kunnen volgen.

Als laatste bevelen we aan meer gebruik te maken van nieuwe methoden zoals geautomatiseerde beeldanalyse, geautomatiseerde spraak en tekstanalyse, en het gebruik van draagbare sensoren om de bewegingen van actoren tijdens de bestrijding van een incident na te gaan. Dergelijke nieuwe technieken helpen om processen en gedragingen in de incidentbestrijding stelselmatig te traceren. Daarmee kan verder worden gezocht naar bewezen verklaringen voor effectieve incidentbestrijding en de veerkracht van vitale infrastructuur.

Curriculum Vitae

Theo van Ruijven (1982) studied Public Administration at Leiden University and Industrial Ecology at Delft University of Technology. During his studies he was a program assistant at the *In Company* training centre of Leiden University, Campus the Hague. He obtained his master degree in Industrial Ecology in 2009 and his master degree in Public Administration in 2010.

From 2009 to 2013 Theo was a Ph.D candidate at the faculty of Technology, Policy and Management of Delft University of Technology. He joined the faculty PhD Council in 2010 and was a member of the Board of PromooD (*the independent representative body for PhD candidates at Delft University of Technology)* from 2011 to 2013. He represented PromooD and the larger PhD community during the development of the TU Delft Graduate School and as the PhD member of the Doctoral Education Committee. In 2013, Theo initiated a track on serious gaming for crisis management at the ISCRAM conference (Vancouver), and chaired the same track at the ISCRAM conference of 2014 (Baden-Baden). He was also a member of the scientific committee of ISCRAM 2014.

Theo worked at Capgemini Consulting as a consultant on public security from 2014 to 2015. He currently works at TNO (the *Dutch Organization for Applied Scientific Research*) as a researcher and advisor on Critical Infrastructure Protection. Theo (co)authored several articles, including:

- Van Ruijven, T., Mayer, I. de Bruijne, M. (2015). Multidisciplinary coordination of on-scene command teams in virtual exercises. *International Journal of Critical Infrastructure Protection*, vol. 9, p. 13-23.
- De Bruijn, H., Groenleer, M., van Ruijven, T. (2015). The dynamics of doping: Lance Armstrong, the United States Anti-Doping Agency and the regulatory governance of professional cycling. *Regulation & Governance*, (in press).
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