Learning within the fire and rescue services – addressing fire and rescue personnel's competence in tunnel fire safety

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Preface

This thesis is submitted with the goal and in fulfilment of the requirements for the degree of Philosophiae Doctor (PhD) at the University of Stavanger (UiS), in the Faculty of Science and Technology, at the Department of Safety, Economics and Planning, in Norway. The work presented in this thesis is the result of research carried out in the period from September 2018 to August 2023 at the UiS and Rogaland Fire and Rescue Services. The compulsory courses were given and attended at the UiS.

The motivation for this work started in 2017, during my master's thesis, which examined road users' knowledge of tunnel fire safety and how the Norwegian authorities facilitate learning and competence development. After the completion of the project, I realized that this was a relatively unexplored area and I had more unanswered than answered questions. For instance, main findings were that tunnel fire safety is not adequately communicated to road users through the driving license training programme and that road users lack knowledge of safe evacuation behaviour in the event of a tunnel fire. road users lack knowledge of safe evacuation behaviour in the event of a tunnel fire. The main challenge was related to the design and implementation of tunnel fire safety educational activities. At this stage, I therefore started to wonder about the capability of the emergency response system to cope with major tunnel fires and how learning and competence development are facilitated.

One year after my master's thesis, in 2018, I received an invitation from Professor Ove Njå to apply for a public PhD programme in Risk Management and Societal Safety at UiS. Instantly, I was very enthusiastic and understood that this project would provide a great opportunity to study in more depth learning and competence within the tunnel fire safety emergency response system. In this PhD project, the research focus has been on learning and competence development within the fire and rescue services, with special attention paid to tunnel fire safety. The main goal has been to gain a better understanding of how fire and rescue personnel learn and develop competence and thus to contribute to some degree of knowledge development in this area. My hope is that results from this

thesis will contribute to an increased interest in learning, support the development of learning activities and educational programmes, and subsequently enhance performance during tunnel fire response.

The process of undertaking a PhD is often compared to that of a lonely journey or a roller coaster. However, it is also a symbol for progress or deeply personal development. Looking back at my journey as a PhD student, I find these descriptions to fit my experiences. The journey has been both deeply challenging and immensely satisfying. The struggle to collect, analyse and display data coherently has taken almost five years. However, I cannot think of any other period of five years in my life where I have experienced such a steep and long learning curve.

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In addition to my supervisors and co-authors, I would like to express my deepest thanks to my mentors and colleagues at the Rogaland Fire and Rescue Services. Thank you for allowing me to participate in your everyday working life, including me in meetings and learning activities and for helping me to develop an understanding of tunnel fire safety practices at the fire department. Your openness, kindness and willingness to share knowledge and experience have been invaluable.

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Summary

Tunnels are a key element of the Norwegian road transport infrastructure. The road tunnel system consists of more than 1200 tunnels with a large variety of safety designs and standards. While many of the Norwegian tunnels are "black holes" in the mountain, located miles away from poorly equipped (i.e., competence, resources) fire departments, other tunnels are more modern and equipped with new technology meant to assist road users and emergency services during rescue and extinguishing operations. Although incident rates are lower in road tunnels than on open roads, the potential consequences of incidents in tunnels are greater by far. This is especially the case in the event of fire, where the enclosed structure and the design of the tunnel hinders the dissipation of smoke and toxic gases and poses difficulty in ensuring safe evacuation for road users. Fire and rescue personnel usually experience high uncertainty, time pressure and high-stake decisions during incidents and fires in tunnels. Too often, they must assess critical features in dynamic environments to determine the best courses of action. Hence, making sense of the situation and understanding mechanisms and interactions in a tunnel fire is challenging and requires personnel equipped with advanced competence. The emergent and dynamic nature of a tunnel fire and the complexity of emergency response operations in road tunnels makes learning and competence development essential aspects of the tunnel fire safety management system.

Workplace learning is an inherent part of fire and rescue personnel's professional development. Both learning through practice and learning through formalized learning activities are crucial for becoming a member of the firefighting team and developing vocational expertise. A main focus in this thesis has been understanding how learning arises through workplace learning activities and practices. Hence, the following main research issue was outlined: *How can fire and rescue services be equipped with adequate principles, models and tools to achieve learning and enhance fire and rescue personnel's competence in tunnel fire safety?*

Four research questions were developed to support the main issue of this study. The research questions were associated with: 1) understanding the

current tunnel fire safety educational framework, 2) investigating fire and rescue personnel's kinds and levels of competence, 3) investigating the properties of a theoretical model for learning in emergency response work in the context of fire and rescue services, and 4) designing learning activities to enrich learning outcomes and increase competence in tunnel fire safety. The research questions were explored through participant observation, a national questionnaire, a comparative study and a pilot course and were addressed in six papers (i.e., studies):

I. A study of the application of a theoretical framework for learning, to assess learning processes based on the cooperation principle, with special attention paid to road tunnels.
II. A study of the application of a systems theory approach to assess the Norwegian tunnel fire safety learning system.
III. A study of the application of a systems theory approach to investigate connections between competence requirements amongst fire and rescue personnel and the tunnels' risk acceptance criterion.
IV. A study of fire and rescue personnel's perceived and actual competence in tunnel fire safety.
V. A study of how learning within the fire and rescue services may be conceptualized, focusing on tunnel fire safety.
VI. A study of the application of a design science approach to develop a pilot course for incident commanders in tunnel fire safety work.

Efficient emergency response management in tunnel fires is highly dependent on effective collaboration and cooperation between the individual members of the firefighting team. Organizational learning is believed to be a major source for enhancing performance. However, studying organizational learning has not been the purpose of this study. The starting point of this study has been that organizations learn through their individual members. Hence, the emphasis has been to examine how the individual member of the firefighting team achieves learning and develops competence.

The theoretical framework for this study (i.e., the cognitive constructivist approach and the socio-cultural approach) has helped to contextualize the studied phenomena, highlight aspects and elements that are important to consider in relation to learning and competence development within the fire and rescue services. A major finding is that the current approach to tunnel fire safety learning has emerged without necessarily being exposed to assessments that stipulate the foundational principles for learning within the fire and rescue services. The work conducted as a part of this thesis illustrates that learning outcomes materialize following two different processes: 1) an internal mental process of acquisition and elaboration, where new knowledge is accumulated, combined and gradually refined through critical thinking, and 2) an external process of interaction and participation in work-related activities under the guidance of more experienced colleagues. Thus, a combined approach to learning is needed to fully understand and explain how fire and rescue personnel learn and develop competence in tunnel fire safety.

Another important finding is that systematic evaluations of learning activities and tools to assess whether and how learning has taken place are generally scarce. Paper I introduces an evaluation tool for identifying and following-up learning effects from cooperation exercises and real-life events, focusing on tunnel fire safety. The evaluation tool suggests that learning outcomes may be expressed as *changes* in structure, cognition, working methods, *confirmation* of knowledge and practices and/or *comprehension* of practices and working methods. They should be identified at different hierarchical levels within the tunnel fire safety emergency response system (i.e., individual level, organizational and interorganizational level, national and international level).

Enhancing the understanding of how the tunnel fire safety learning system can be modelled to increase fire and rescue personnel's competence is essential for the fire and rescue services' safety management system. Papers II and III discuss the current tunnel fire safety educational framework and recommend a framework for enhancing competence using a systems theory approach and a model for learning in emergency response work. The studies suggest that the frame conditions for developing efficient learning systems are not yet in place and that the current approach leads to narrow understanding of tunnel

fire safety learning practices. The fire and rescue services acknowledge learning activities as fundamental to safety improvement efforts and ensuring that incidents in tunnels are handled adequately. Different kinds of learning activities exist, but there is a gap in the design of the curricula with respect to learning goals, content, instructional techniques and the requirements for effective performance during incidents in tunnels. Overall, it is suggested that development and enforcement of competence constraints for personnel involved in tunnel fire safety work are necessary.

Understanding the capability of the fire and rescue services is an essential aspect of the tunnel fire safety management system. Paper IV assesses fire and rescue personnel's self-evaluations of competence (i.e., perceived) against their taught competence (i.e., actual). An important finding in this study is that the personnel's kinds and levels of competence vary significantly and that there are discrepancies between the taught practices and the strategies and practices enacted by the personnel when responding to fire events in tunnels. Based on the findings and insights following the analysis of the discrepancies, it is proposed that the content of learning activities should place considerable emphasis on developing decision-making skills and problem-solving abilities so that the personnel are able to read situational cues and assess which choices of action are appropriate to enact during tunnel fire responses.

Paper V investigates the properties of a theoretical model for learning in emergency response work and the significant mechanisms that influence the outcome of the learning process (i.e., change, confirmation, comprehension). Findings from this study provide empirical evidence and show that the outcome of the learning process is influenced by the *content* of what is being learned, the *context* where learning takes place, fire and rescue personnel's *commitment* to learning activities, involvement in *decision-making and respons*e and *reflection*. In addition, reflection is revealed to be the driving force behind the learning process.

Theoretical anchoring, the understanding of significant mechanisms and foundational principles for learning are key requirements when designing learning activities and educational programmes aimed at

enhancing fire and rescue personnel's competence in tunnel fire safety. Paper VI illustrates how key learning mechanisms and a design science approach can be integrated to develop a course for incident commanders involved in tunnel fire safety work. For instance, experiences from this study indicate that learning and competence development are derived not from abstract thought, or by thinking and acting uncritically, but rather by integrating thinking and acting through theory and practice and by getting the personnel to critically reflect upon their decisions and response actions. Working with realistic scenarios that progressively increased in complexity in groups and across experiences stimulated constructive debates and discussions questioning the fire department's approach to tunnel fire safety and the prevailing tactics and strategies.

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List of Abbreviations

ACS	Analyses of Crisis Scenarios
AID	Automatic Incident Detection
ANOVA	Analysis of Variance
CBRNE	Chemical, Biological, Radiological, Nuclear and Explosive Materials
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
DAB	Digital Audio Broadcasting
DCP	Directorate for Civil Protection
EFA	Exploratory Factor Analysis
HAZID	Hazard Identification
HGV	Heavy Goods Vehicles
KMO	Kaiser-Meyer-Olkin
MMR	Mixed Methods Research
NCRD	Norwegian Centre of Research Data
NDM	Naturalistic Decision Making
NFRA	Norwegian Fire and Rescue Academy
NPRA	Norwegian Public Roads Administration
NSIA	Norwegian Safety Investigation Authority
OAGN	Office of the Auditor General of Norway
PCA	Principal Component Analysis

RMSEA	Root Mean Error of Approximation
RPD	Recognition Primed Decision
RQs	Research Questions
RTC	Road Traffic Centre
SEM	Structural Equation Modelling
SPSS	Statistical Package for Social Science
SRMR	Standardized Root Mean Square Residual
TLI	Tucker-Lewis Index
USAR	Urban Search and Rescue

Definitions

This section provides a brief explanation of the key concepts that are used in this study. Those concepts which are not referenced are developed from the literature and the theoretical perspectives are presented in this thesis.

Competence

Individuals' ability to deal appropriately with a challenge in a particular context. The challenge is a non-routine task and not reflected in specific success criteria but, rather, context-dependent and reflected as an open result to individuals' decisions and response actions (Illeris, 2017).

Constructivism

A philosophical paradigm that sees scientific work and knowledge as constructed by individuals who can never escape their emotions, beliefs and values and can therefore never be authentically objective (Fosnot, 2005).

Emergency response operation

Systematic process for preventing or reducing the harmful effects of incidents that have occurred (Njå, 1998).

Experience

An accumulated repertoire of ways to apply knowledge and skills to solve complex problems within a specific context.

Experts

Those individuals from whom others seek advice about how to approach a difficult task. Their attributes differentiate them from less experienced workers and are also the qualities that other workers aspire to.

Knowledge

Interpretation of things, situations and actions which are context-bound and a product of individuals' sense-making. Knowledge is not discovered but rather created; it exists only in the time/space framework in which is generated (Fosnot, 2005).

Learning

A process that contributes to changes in structures, behaviours, cognition and processes, confirmation of existing knowledge and practices and comprehension of established practices, tools, behaviours or working methods (Njå & Braut, 2010).

Reflection

A processing phase, in which individuals consciously think about a concrete experience, assess what happened and evaluate the response (Boud et al., 1996).

Tunnel fire safety

Designing safety management systems that prevent or eliminate the occurrence of fires or minimize the consequences of a tunnel fire for road users and other groups of people involved.

Part I

1 Introduction

A valuable thesis about learning within the fire and rescue services, focusing on fire and rescue personnel's competence in tunnel fire safety, is, in my opinion, a thesis about how to facilitate the process of learning, to develop fire and rescue personnel's knowledge and skills to react in a satisfactory way during emergency response operations in tunnels. Is the current approach to learning adopted by the fire and rescue services appropriate to meet the challenges and the complexity that major tunnel fires represent?

Traditionally, the concept of learning has been associated with formal educational settings, whereas its use in the context of the workplace for developing vocational expertise is a relatively new phenomenon. From a perspective that advocates learning in educational institutions, concerns have been expressed that learning outside formal educational settings is informal, ad hoc, weak, concrete and incidental (Marsick & Watkins, 1990). Billett (2004) has challenged these descriptions of workplace learning, claiming that workplace activities are highly structured and directed towards continuity, in ways that are inherently pedagogical. The work presented in this thesis refers to workplace learning as learning situations embedded in fire and rescue personnel's conscious cognitive activities and their everyday work practices (Billett, 2004; Hager, 2011; Lave & Wenger, 1991). Further, to investigate how fire and rescue personnel learn and develop competence, workplace learning is approached by placing the individual at the centre of learning in organizations.

Within the context of fire and rescue services, learning relates mostly to improving performance, to ensure that the personnel choose appropriate tactics and strategies during emergency response operations. Learning is secured through socially constructed workplace practices and experiences (e.g., responses to incidents, activities between responses, participation in educational programmes and training exercises), and usually through means quite distinct from the learning that occurs in formal educational settings. At the heart of improving learning lies the challenge of bringing together learning through practice and learning through formalized learning activities. Understanding how learning

arises through workplace practices and formalized learning activities requires particularly explanatory premises about – and conceptions of – these phenomena.

In the Analyses of Crisis Scenarios (ACS), a series of plausible worst-case scenarios are analysed (DCP, 2019). The Directorate for Civil Protection (DCP) emphasizes that these are scenarios with catastrophic consequences for Norwegian society. Further, it is expected that the responsible authorities and organizations systematically follow up and include these analyses in their emergency preparedness work. For instance, since 2014, *Pandemic* has been outlined as a national crisis scenario with a high probability of occurrence and severe consequences. However, evaluation of the pandemic management showed that the authorities were not prepared when the widespread and severe COVID-19 arrived (NOU, 2021:6). Also, *Tunnel fire* has been identified as a potential crisis scenario. The fire and rescue services have an essential role with regard to both preventing and handling the consequences of tunnel fires. Sufficient competence amongst fire and rescue personnel is therefore a prerequisite, to ensure that incidents in tunnels are handled adequately and to avoid the catastrophic consequences of major tunnel fires. However, several studies have revealed that tunnel fire safety is an unprioritized area in educational settings, and that fire and rescue personnel's competence varies substantially across the Norwegian fire and rescue services (Njå & Svela, 2018; Bjørnsen & Njå, 2019; Bjørnsen et al., 2023). The studies have also demonstrated that the fire and rescue services lack knowledge of safety systems in tunnels and that their specific knowledge of tunnels is limited.

Tunnel fire safety work for personnel involved in emergency responses in complex tunnel systems contains many challenges. For instance, fire and rescue personnel are the first responders at the incident site, dealing with the tunnel fire situation. During response operations, overall command is assigned to the incident commander, who is responsible for outlining strategies and choosing tactics. At an early stage of the fire, the consequences may be unclear, and the decisions made in the first minutes are crucial for the outcome of the incident. For instance, should the response strategy prioritize combatting the fire or conducting search and rescue for road users inside the tunnel? Dynamic reviews of behaviours,

decisions and tactical plans are essential, to monitor the changing risk level of the situation and evaluate the effectiveness of the implemented actions. Situation awareness is acknowledged as a key requirement for effective decision-making in emergency response activities (Flin et al., 2008). In tunnel fires, a dangerous environment can rapidly escalate. Thus, monitoring the fire escalation, smoke dispersion, available resources, traffic picture and position of evacuating road users is essential.

The work behind this thesis builds on previous research studies conducted within the Norwegian fire and rescue services (Njå & Svela, 2018; Rake, 2008; Sommer, 2015). Rake (2008) explored how emergency response units can be managed to cope successfully on-scene during an accident and subsequently increase the efficacy of emergency management during responses. Sommer (2015) investigated learning in emergency response organizations, with an emphasis on how individuals learn to carry out emergency response work. Lastly, Njå and Svela (2018) assessed first responders' competence in tunnel fire responses, focusing on how fire and rescue services express uncertainties and expectations, and paved the way for the present study.

This study focuses on learning within the fire and rescue services, to better support, plan and organize learning processes to enhance fire and rescue personnel's competence (i.e., knowledge and skills) in tunnel fire safety. A major contribution to knowledge from this thesis is insights into fire and rescue personnel's competence. These insights emerged from investigating and contrasting first responders' perceived and actual competence. Further, another contribution to knowledge is increased understanding of the mechanisms that are most likely to promote learning and of how learning activities can be designed to enrich learning outcomes and enhance fire and rescue personnel's competence in tunnel fire safety.

1.1 Emergency response operations in complex road tunnel systems

During the 20th century, advances in science, the emergence of new technology and societal changes altered the way we live our lives and the

way we work, as well as creating new and increased hazards (Funtowicz & Ravetz, 1992; Leveson, 2011). A consequence of the changes and the rapid development of today's society is increased complexity and coupling in the systems we are building (Perrow, 1999). As society becomes more complex, so too do the occupational tasks of fire and rescue personnel, and the knowledge and skills acquired during the initial education are no longer sufficient. Complexity increases the demand on flexibility, communication and teamwork and requires abilities to put that knowledge and those skills to use in unfamiliar circumstances (Boud & Garrick, 1999). Fire and rescue personnel must know which tactical plans and strategies to implement in which situations, be familiar with workplace practices and how to perform them satisfactorily and assess their performance (Njå & Sommer, 2010). Since learning situations will never be identical to real emergency situations, learning activities should seek to ensure that the personnel are able to generalize the acquired knowledge to situations that resemble the experiences provided through the learning activities (Njå, 1998; Sommer & Njå, 2011).

Every tunnel fire rescue operation is unique and comes with its own set of problems and challenges. The challenges may relate to several aspects, such as inaccurate understanding of the tunnel's design and the functionality of the safety equipment, the involvement of several actors and organizations cooperating in crises situations and the ability of the personnel to predict the scenario's development based on the available information (Bjørnsen & Njå, 2019; Bjørnsen et al., 2023). Experience from the Oslofjord tunnel fire has shown several difficulties related to communication between the emergency response services, road traffic operators and road users (Njå & Kuran 2015; NSIA, 2013). For instance, based on the information acquired in the initial phase, the operational commander decided to start the extinguishing operation immediately and had no time to stop outside the tunnel and collect additional information. However, during the extinguishing work, an unforeseen development occurred because of an explosion caused by a cannister containing propane, and the firefighting crew was engulfed in smoke.

Worldwide, the number of road tunnels has increased significantly over the last two decades, and all indicators signalize that the number will continue to increase in the upcoming years. In Norway, road tunnels are

a key element in the road traffic system, and the road infrastructure consists of more than 1200 tunnels. Amongst these, 186 are longer than 2 kilometres and 41 are subsea tunnels with steep slopes (>5%). These tunnels comprise 5% of the length of the Norwegian road tunnels and are overrepresented in statistics of vehicle fires (Nævestad et al., 2016). Steep slopes, length, annual average daily traffic of heavy goods vehicles (HGV), and whether a tunnel is subsea are the major factors that contribute to HGV fires in tunnels (Njå et al., 2022). Currently, several innovative tunnel projects are under construction, including the world's longest subsea road tunnel, which is planned to be completed in 2033 in Rogaland. The Rogfast tunnel is expected to be 26.7 kilometres long, dual tube, 390 metres below sea level at the deepest point, with a maximum gradient of 5%. To provide access to the island of Kvitsøy, the tunnel will feature a junction in the middle and a 3.5-km single-tube tunnel. The junction consists of entry and exit ramps, with two roundabouts above the main tunnel.

A common feature of Norwegian tunnels is that they represent great variety in design and level of safety (Njå, 2017). For instance, many tunnels are "black holes" in the mountain, located miles away from poorly equipped voluntary fire departments. In the event of fire, the only emergency exits are the tunnel portals, and road users must evacuate long distances under extremely difficult conditions. Nowadays, many would argue that the level of safety has increased considerably, due to the construction of new tunnels and projects upgrading existing tunnels. Modern tunnels are packed with technology (e.g., ventilation, emergency exits, lighting, drainage, fire extinguishers, traffic installations, surveillance systems, communication systems, etc.) meant to assist fire and rescue services during response operations and road users immediately when unwanted situations occur. Nevertheless, introducing new technology and coupling more systems in existing systems generates a new level of complexity (Bjelland et al., 2021).

A highlighted argument is that, while old systems, sub-systems and components were largely segregated and loosely connected, modern systems are integrated – causing interactions and dependencies that are both unanticipated and unwanted (Leveson, 2004, 2011; Perrow, 1999). The Ryfast tunnel system consists of three dual-tube unidirectional

tunnels equipped with advanced safety systems and technology. Interestingly, in 2020, a vehicle fire occurred in the Hundvåg tunnel and revealed that road users and the emergency services may behave differently than expected. For instance, despite the information received from the emergency central operators, road users chose not to evacuate the tunnel through the emergency exits but to turn their vehicles inside the tunnel and create an unsafe environment for the fire and rescue units on their way to the incident site.

Although incidents in tunnels have a lower frequency than incidents on open roads, the potential damage a single incident may cause is greater by far (Nævestad et al., 2016). This is especially the case in the event of fire, where the enclosed space hinders the dissipation of smoke and inhibits the possibility of ensuring a safe escape route for road users. Emergency response operations in tunnels involve a large number of technical aspects and actors (e.g., fire and rescue, police, health, road authorities, traffic operators, emergency operators and road users), whose individual actions, and interactions with each other, will influence the outcome of the situation. Different practices and understandings of how to approach the incident, as well as language and cultural differences between the involved parties, are factors that may lead to misunderstandings and negatively affect the outcome of the emergency response. It is a complicated picture, and the success of the emergency response is dependent on collaboration between the tunnels' technical, organizational, social and managerial dimensions.

As Norway has many long and complicated road tunnels, a major challenge for fire and rescue services involved in tunnel fire operations is to facilitate fast and effective responses that protect road users from harmful conditions. Road users' expected behaviour in tunnel fires is based on the *self-rescue principle*. This means that road users exposed to a tunnel fire must evacuate the tunnel by their own means and cannot rely on rescue by the emergency services. Njå and Kuran's (2015) study of the 2011 fire in the Oslofjord tunnel reported that road users claimed that they became engulfed in heavy smoke due to the fire and rescue personnel's decision to increase the ventilation flow towards their location in the tunnel.

During the last decade, Norway has experienced several serious tunnel fires (e.g., the Oslofjord tunnel fires in 2011 and 2017, the Gudvanga tunnel fires in 2013 and 2015, the Skatestraum tunnel fire in 2015, the Fjærland tunnel fire in 2017). So far, no lives have been lost in Norwegian tunnel fires and the subsequent smoke exposure. However, in more or less every fire scenario, road users were exposed to smoke and suffered serious injuries caused by inhalation of smoke and toxic gases (NSIA, 2013, 2015, 2016a, 2016b). Societal expectations regarding enhancing safety in tunnels and ensuring that incidents are handled adequately are high. The Norwegian Safety Investigation Authority (NSIA) has critically investigated these incidents and raised concerns regarding the safety level in tunnels, and the response capability of emergency services has been criticized. The reports point to several challenges, such as: lack of focus on the self-rescue principle, insufficient understanding of fire ventilation, inadequate communication between the emergency response services, and deficient emergency response plans. An overall conclusion of the investigations is that, under slightly altered circumstances, each of these fires could have resulted in casualties. The Office of the Auditor General of Norway (OAGN) has also addressed similar concerns and claimed that there is an urgent need to improve tunnel fire safety and the capability of emergency response services (OAGN, 2016).

Much research has been devoted to assisting emergency service organizations to better understand how to facilitate more efficient and effective learning (Andersson, 2016; Borell & Eriksson, 2008; Dekker et al., 2008; Owen et al., 2018; Sommer et al., 2013; Sommer & Njå, 2011). For instance, Dekker et al. (2008) studied the ability of fire departments to learn during emergency responses and found that they often lacked basic organizational prerequisites for effectively learning from failures (i.e., mutual trust, participation and knowledge of possible learning mechanisms). Sommer and Njå's (2011) study of learning amongst Norwegian firefighters concluded that learning can be improved by actors becoming more reflective practitioners, where responses are critically assessed, and established knowledge and work practices are debated. Andersson (2016) examined mechanisms for learning in emergency exercises and discovered that boundaries, such as vocabulary, prioritization, roles, knowledge gaps and overlapping

responsibilities, can be utilized in exercises to support learning. Owen et al.'s (2018) study of learning in emergency service organizations found that, to enhance learning, organizations must shift value from after-action reviews to reflection, focusing on the bigger picture and allowing enough time to effectively embed new practices after an emergency.

1.2 Research aim

Based on the discussed aspects, it may be questioned how the emergency response system approaches learning to ensure adequate performance during response operations in tunnels. The overall research aim of this thesis is, therefore, to gain new knowledge of how to facilitate learning processes within the fire and rescue services and enhance fire and rescue personnel's competence in tunnel fire safety. It is of great interest to gain knowledge about principles, models and tools to address learning in emergency response work and thereby contribute to improved safety and emergency response management in road tunnels. In this study, *principles* refer to theoretical frameworks for understanding and facilitating learning processes within the fire and rescue services. Subsequently, these principles are understood and interpreted in relation to tunnels as special risk objects. Furthermore, *models* refer to constructions based on empirical knowledge that may help to understand individual learning in emergency response work and develop and evaluate learning activities. Finally, *tools* seek to capture educational mechanisms (i.e., role-play exercises, table-top exercises, theoretical lectures) that should be incorporated in the design of learning activities.

1.3 Main research issue and research questions

To address the research aim and direct guidance during the research, the following main research issue was developed:

How can the fire and rescue services be equipped with adequate principles, models and tools to achieve learning and enhance fire and rescue personnel's competence in tunnel fire safety?

The main research issue comprises a relatively broad area of research, in terms of asking how to achieve *learning* and enhance fire and rescue personnel's *competence* in *tunnel fire safety*. Workplace learning can be analysed as a process taking place at different levels, more precisely from the levels of individuals and groups to the levels of communities of practice, organizations and inter-organizational networks (Tynjälä, 2008). When talking about learning, a prevalent distinction is that of individual learning (Illeris, 2010; Ormrod, 2008) and organizational learning (Argyris & Schön, 1996; Senge, 2006). Theories of individual and organizational learning emphasize different theoretical foundations regarding the nature of learning and how learning occurs. Different understandings are suitable for different kinds of contexts.

Within the context of fire and rescue services, learning takes place as participation in organized learning activities, training exercises, everyday work practices and responses to emergency situations. Effective emergency response management in tunnel fires is highly dependent on efficient leadership, communication and cooperation between the individual members of the firefighting team (Bjørnsen et al., 2023). Learning situations, therefore, seek to improve the firefighting team's capability during emergency responses and realize the overall organizational goal – ensuring the safety of inhabitants and saving human lives. Much of the literature in the field of emergency response management emphasizes organizational or team aspects (Andersson, 2016; Borell & Eriksson, 2008; Dekker et al., 2008; Hovden et al., 2011; Lonka & Wybo, 2005). However, organizational learning is considered to require individual members to learn for the organization (Argyris & Schön, 1996; Dixon, 1999; Senge, 2006). Since individuals operate in the learning society and organizations, changes in individual cognitive processes and behaviour, as well as changes in social systems, are considered to depend on contributions from individuals. Thus, when analysing learning in larger groups (i.e., teams, organizations, societies) it is important to understand learning at the individual level.

In this thesis, the individual is the point of departure for analysing how workplace learning may be achieved. Moreover, learning is seen as a highly contextualized phenomenon that takes place in the individual's mind. While the first idea relates to learning as a process emerging from

the individual's interaction with the working environment (Lave & Wenger, 1991; Wenger, 1998), the second idea directs the attention towards the cognitive processes of acquisition, through which new impulses are connected with prior experiences (Anderson, 1982; Illeris, 2011; Piaget, 1997).

In literature, a significant confusion is linked to the inconsistent use of the terms 'qualification' and 'competence'. As regards this ambiguity, it is necessary to distinguish between these terms and clarify how the term 'competence' is understood. Generally, the terms denote aspects of occupational requirements for fire and rescue personnel, so that emergency response operations are handled successfully. In workplaces, the term 'qualification' has its roots in industrial sociology and describes occupational requirements for a certain class of work tasks (Ellström, 1997; Illeris, 2009a). 'Competence', in contrast, has its background in organizational psychology and modern management thinking and is *"a unifying concept that integrates everything it takes in order to perform in a given situation"* (Illeris, 2009b, p. 21). Illeris also associates the term with individuals' *"ability to lead in complex and unforeseen situations, in different contexts"* (p. 21). Influenced by this understanding, competence is used to describe the capability of fire and rescue personnel to successfully handle potential emergency response situations in tunnels, while qualification is something that can be drawn in to assist in realizing the necessary competence.

Within this context, a central question is: what competence should fire and rescue personnel possess? For instance, fire and rescue personnel's competence in case of a tunnel fire may relate to: knowing the design of the tunnel and its safety systems, assessing the situation based on the available information and implementing adequate tactics and strategies, achieving common situational awareness, ensuring lifesaving activities, facilitating conditions for self-rescue and evacuation, ensuring their own safety, assessing the need for resources, performing fire extinguishing work and search and rescue activities, as well as communicating and cooperating with other emergency response services.

Norwegian society expects the fire and rescue services to effectively manage both minor and major incidents in tunnels when they occur. Tunnel fire safety is understood *"as freedom from unacceptable losses*

as identified by the system stakeholders" (Leveson, 2020, p. 27). From this point of view, tunnel fire safety is freedom from conditions that may lead to death or injuries to human lives or damage to the environment. Tunnel fire safety is about designing safety management systems that prevent or eliminate the occurrence of fires or minimize the consequences of a tunnel fire for road users and other groups of people involved.

Based on the aspects described above, in the initiating phase it was considered important to acquire an understanding of the frame conditions behind the organization of the tunnel fire safety educational framework and how learning and competence are approached by the fire and rescue services. This generated the development of the first research question:

- *Research question 1*: How do the current educational framework and learning activities approach learning and competence, given that response operations in tunnels represent high-risk and challenging situations? (Papers I, II and III)

A major motivation for developing and implementing tunnel fire safety learning activities is to equip fire and rescue personnel with the ability to deal effectively with complex and hazardous situations in tunnels. Searching for answers to this research question solely within individual learning theories seemed limited. For instance, it was also important to understand how safety-related issues may be integrated within the tunnel fire safety learning system in which the individual firefighter operates. Nancy Leveson's (2011) systems theory approach to safety provides an understanding of how to deal with complexity in socio-technical systems and was regarded as highly relevant. For instance, the diversity of actors and components involved in the design and operation of the tunnel fire safety learning system comprises technical, organizational and managerial aspects. To ensure safety, effective communication mechanisms are needed that transmit relevant information and provide feedback about the efficacy of the learning activities.

The work associated with research question 1 is of a descriptive nature and investigates the following issues: How are the current tunnel fire safety learning activities implemented and followed up by Norwegian fire and rescue services? Which connections are established between

competence constraints amongst fire and rescue personnel and the tunnels' risk acceptance criterion? Since assessments of learning were of crucial importance, it became also a first focus area of the research. Thus, a first objective of the research was to understand learning processes within the fire and rescue services and develop a tool for identifying and following up learning effects from learning activities. To approach this research question empirically, participant observation was carried out in a major fire department with its own tunnel fire safety educational programme. Participant observation was used to gain insight into the design and operation of the tunnel fire safety learning system within the fire and rescue services.

Furthermore, it was of interest to investigate kinds and levels of competence in tunnel fire safety amongst fire and rescue personnel. While available resources and established procedures play a key role in the safe and successful outcome of a tunnel fire response, the critical element is, without any doubt, the human factor, expressed in terms of the personnel's competence. The concepts of 'perceived' and 'actual' competence were employed, with the scope of analysing differences between fire and rescue personnel's self-evaluations of competence and their actual competence. This gave rise to the following research question:

- *Research question 2*: How do employees in the Norwegian fire and rescue services regard their own competence, and to what extent do their self-evaluations of competence reflect the actual level of competence within the Norwegian fire department? (Paper IV)

In this thesis, in line with Illeris' (2009b) understanding, competence is primarily discussed with reference to individuals' ability to meet a challenge in a particular and unforeseen context. To capture the Norwegian fire and rescue personnel's self-evaluations of competence regarding responses to fires in tunnels, a national questionnaire was carried out. Further, to understand more fully the actual level of competence, it was necessary to conduct a comparative study in a major fire department with several high-risk tunnels in its area. From this background, this thesis was narrowed to investigating fire and rescue personnel's competence by examining their response practices when

confronting hypothetical fire events in tunnels. These response practices are reflected through the strategies and priorities of tunnel fire safety work in which the personnel chose to engage.

The emergency response systems are designed partly on self-regulation principles, which encourage creative solutions. Fire and rescue services must therefore facilitate and promote conditions that aim to develop optimal learning systems. Thus, another focus area of the research was to gain a comprehensive understanding of the process of learning within the fire and rescue services. Previous studies have developed a model to understand learning in emergency response work (Braut & Njå, 2009; Njå & Braut, 2010; Sommer et al., 2013). The third research question investigated the properties of the learning model and the mechanisms that are most likely to promote learning.

- *Research question 3*: What mechanisms are significant determinants to facilitate the process of learning within the fire and rescue services, and how is the outcome of learning affected by these mechanisms? (Paper V)

Learning within the emergency response system has been thoroughly studied by several researchers through organizational learning theories (Andersson, 2016; Borell & Eriksson, 2008; Dekker et al., 2008; Hovden et al., 2011; Lonka & Wybo, 2005). However, learning in emergency response systems through individual learning theories remains to be researched more closely. In line with Braut and Njå's (2009) and Njå and Braut's (2010) theoretical framework of learning in emergency organizations, this thesis assumes the process of learning to consist of six interrelated elements, such as *content*, *context*, *commitment*, *decision-making and response, reflection* and the *outcome of learning*, expressed as *changes*, *confirmation* and/or *comprehension*. To approach this research question empirically and capture manifestations that may provide information about the phenomena under study, a national questionnaire was carried out. This provided large amounts of data and allowed for statistical procedures to evaluate the learning model and the connections between its elements.

While the three first research questions are of a descriptive nature, the final research question has a normative nature and addresses the design of a course for incident commanders. Research question 4 was developed

to investigate the design process behind a newly developed course for incident commanders:

- *Research question 4*: How can learning activities successfully be designed to enrich learning outcomes and enhance fire and rescue personnel's competence in tunnel fire safety? (Paper VI)

Here also, searching for answers to this research question solely within individual learning theories seemed limited. For instance, it was crucial to gain knowledge about how to support the design of learning activities and generate methodological instructions for the iterative development and evaluation of the learning activities' performance. Design science aims to construct models, methods and implementations that are innovative and valuable (March & Smith, 1995). The literature offers an empirical foundation with regard to how designers may think and act and how design processes evolve. From this background, it was decided to include elements from design science literature. To approach this research question empirically, a pilot course for incident commanders was carried out. Furthermore, insights gained from participant observation, the national questionnaire and the comparative study provided valuable knowledge that aided the development of the pilot course.

The major results are presented in Chapter 5 and in the papers in Part II.

1.4 Structure of the thesis

This thesis consists of two parts. Part I contains seven chapters. Chapter 1 introduces the background of this thesis, framing the main research issue and related research questions, including this thesis' limitations. It also discusses the challenges that fire and rescue personnel face during emergency response operations in tunnels. Chapter 2 describes the context in which learning and competence development occurs and the challenges that fire and rescue personnel face in tunnel fires. Chapter 3 contains a presentation of the theoretical framework that was relevant for studying learning and competence within the fire and rescue services. Chapter 4 presents the methodology used in this thesis, while Chapter 5 presents the main findings of this research work. Chapter 6 discusses the main findings, the contribution of this research work and the research

quality. Chapter 7 summarizes this thesis and provides recommendation for further research.

Part II contains the six research papers that are included in this thesis:

I. Bjørnsen, G., Njå, O. & Braut, G.S. (2020). A tool to assess learning processes based on the cooperation principle. In J.P. Liyanage, J. Amadi-Echendu & J. Mathew, (Eds.) *Engineering assets and public infrastructures in the age of digitalisation*, pp. 87-95. Springer.

II. Bjørnsen, G., & Njå, O. (2019). Applying systems theory to increase competence in tunnel fire safety – Focusing on the fire and rescue services. In *Proceedings of the 29th European Safety and Reliability Conference (ESREL)*. Hannover.

III. Bjørnsen, G., & Njå, O. (2020). Competence constraints for fire and rescue personnel involved in tunnel fire safety as part of the tunnels' risk acceptability. In *Proceedings of the 30th European Safety and Reliability Conference and 15th Probabilistic Safety Assessment and Management Conference (ESREL2020 PSAM15)*. Venice.

IV. Bjørnsen, G., Billett, S., & Njå, O. (2023). First responders' perceived and actual competence in tunnel fire safety. *Fire Safety Journal*, 136, 103758.

V. Bjørnsen, G., Dettweiler, U., Njå, O., & Knudsen, K. (2022). Towards an understanding of learning within the Norwegian fire and rescue services – Focusing on tunnel fire safety. *Journal of Workplace Learning*, 35 (1), pp. 112-128.

VI. Bjørnsen, G., & Njå, O. (2023). Vocational learning of incident commanders in tunnel fire safety work. *Australian Journal of Adult Learning: Contributions of workplace experiences to adults' lifelong learning.*

2 Setting the context

The core task of the Norwegian fire and rescue services is to protect human lives, health, environment and material values against fires, explosions, incidents with hazardous materials and other unexpected incidents (MJPS, 2021). This means that fire and rescue personnel are confronted with a large variety of issues during emergency response situations, for instance, fire extinguishing, first aid and patient treatment, extraction of victims from traffic accidents, handling released hazardous materials, handling natural disasters (i.e., forest fire, flood, landslide), as well as other search and rescue actions both on land and in water. Recently, a working group has reviewed the fire and rescue services and pointed out that, as a result of demography, climate change, economics, technological development and the green shift, the frequency and complexity of unwanted events will increase and challenge the capacity of fire and rescue services (Ly et al., 2023). Hence, more advanced equipment and new competence requirements should be considered in the future organization and education of fire and rescue services.

To ensure sufficient capability, the *Regulation concerning the organization and dimensioning of the fire and rescue services and the emergency centrals* sets minimum requirements for the organization, personnel, equipment and competence of the fire and rescue services (DCP, 2022). Further, to ensure that the emergency response capability is adapted to the tasks and risks the local fire department is likely to meet, it is required to develop risk analysis, preventive analysis and emergency response analysis. Together, these analyses constitute the basis for how the local fire department shall be organized, staffed and equipped. It is emphasized that the municipalities are responsible for ensuring that all personnel possess sufficient qualifications and for developing learning plans for each of the employees to achieve this goal. In the context of tunnel fire safety, there are no specific requirements regarding fire and rescue personnel's competence, besides the general requirements of their occupation. This means that the local fire department must establish adequate principles, models and tools for the learning and training of the personnel.

In Norway, the fire and rescue services are governed by the municipalities, ranging from only 200 inhabitants to 700,000 at the largest. Previously, each municipality had its own and independent fire department. However, nowadays the fire departments tend to organize themselves as larger fire departments, covering several municipalities and structured as inter-municipal organizations. In 2023, the fire and rescue system consisted of 197 fire departments (Ly et al., 2023). Norway has a great variation in topography and population settlement. The population is concentrated in relatively limited areas, mainly in the central eastern part and around larger cities along the coast. This variety generates significant differences in relation to how the fire and rescue services are organized and equipped. Furthermore, it influences the capability of the local fire department to carry out emergency response tasks, as well as the kinds of tasks and levels of competence with which they are performed. The smallest fire department provides services that cover less than 3,000 inhabitants, while the biggest covers more than 250,000. Of the approximately 12,000 employees in the Norwegian fire and rescue system, 8,000 are employed in part-time positions and 4,000 in full-time positions.

A main difference between the fire departments is whether they operate as 24-hour staffed departments or as part-time departments, staffed with personnel activated in the case of emergencies. As most incidents occur in municipalities with large populations, there are major differences between full-time and part-time departments in terms of occupational tasks and use of working time. For instance, full-time departments are involved in far more incidents than part-time departments, use their working time differently and offer more specialized services (e.g., chemical, biological, radiological, nuclear and explosive materials (CBRNE), urban search and rescue (USAR), rescue diving, tunnel fire, animal rescue). Furthermore, part-time personnel are usually employed in very small hourly percentages (0.96 – 5.2%) and therefore have limited time allocated to knowledge and skills' development (Ly et al., 2023). Importantly, it should also be specified that the trend towards population settlement in larger municipalities causes challenges for fire departments organized as part-time services regarding personnel recruitment. A main challenge is related to the fact that candidates do not live close enough for the fire department to meet the emergency response

time requirement. This means that many fire departments are "understaffed" and that their response performance varies significantly.

The Norwegian Fire and Rescue Academy (NFRA) is the national educational institution for fire and rescue personnel and the main supplier of learning goals, educational content and instructional techniques (NOU, 2012:8). The learning system is based on the idea of training and education after employment. Further, the career system seems to be more or less guided by years of experience than specific educational qualifications. Personnel usually start as aspirants and gradually work their way up in the system to become leaders at different levels in the organization. Much of their knowledge and skills is therefore acquired through socially constructed workplace practices and experiences, which are accumulated during responses to emergency situations and training exercises. Workplace learning is an inherent part of the various fire departments but is rarely reflected in terms of how it contributes to learning and the subsequent levels of competence.

The formal education for fire and rescue personnel must be completed during a period of two years and consists of internal training, an online course and a basic course (NOU, 2012:8). The internal training is the initial education and takes place at the local fire department where the individual firefighter is employed. The aim is to ensure adequate competence so that the personnel can carry out basic fire and rescue work. Training is mostly on-the-job and facilitated by experienced firefighters (i.e., instructors). It includes teaching the fire department's different tools and equipment, routines, procedures and practices for firefighting and rescue work. It is not usually common for a novice to question the teaching and instructions provided, and he/she needs to adapt to the experienced firefighters' way of working.

After the internal training offered by the local fire department, the education is supplemented by a basic course at the NFRA. The basic course consists of, respectively, eight weeks with theoretical lectures and practical exercises for full-time personnel and five weeks for part-time personnel. For part-time personnel, most of the course is organized as self-study, evening and weekend gatherings under the auspices of the local or regional municipality. The content of the course addresses

interpersonal relations, fire safety topics, rescue topics, smoke diving and incidents with hazardous materials (NFRA, 2019). Before personnel can attend the basic course, they are required to complete an online course of fire protection. This course introduces fire prevention and emergency response tasks.

To strengthen the education of fire and rescue personnel, a public two-year vocational school is being established (Ly et al., 2023). The new education system seeks to facilitate future-oriented education and provide basic knowledge and skills, so that the personnel are capable of working with various tasks. However, for personnel employed in part-time positions there are no requirements for completed vocational education, and the responsibility for their education still rests on the local fire department but with increased support from the NFRA. It should be specified that much of the education conducted within the local fire department depends on the individual firefighters' efforts, motivation and competence. Hence, the individual firefighter must be capable of planning and carrying out learning activities and motivate the personnel to participate in these. Furthermore, competence development through experiential learning, especially from complex emergency response situations (i.e., major tunnel fires), is difficult for personnel employed in part-time positions to achieve. This challenge relates to both the time allocated to knowledge and skills' development, as well as the number of emergency response situations that may provide learning through experience.

Although the legal framework offers some formal requirements for how to work with tunnel fire safety, these requirements are seldom made explicit. The trend towards larger fire departments spanning several municipalities generates variations in how tunnel fire safety is understood. For instance, some fire departments responsible for tunnels at risk in their region express concerns about the challenges related to tunnel fires, while others are less concerned about the risks and consider tunnel fires no more challenging than fires on open roads. Furthermore, the absence of major tunnel fire events involving loss of life and serious injuries influences how the national and regional authorities distribute resources within the emergency response system. For instance, major incidents that receive attention amongst the authorities provide

possibilities for the fire department to facilitate competence-enhancing activities and acquire new equipment.

2.1 Why tunnel fire safety is challenging for fire and rescue personnel

Fire in an HGV, with the potential for cascading effects, in long subsea tunnels is a plausible worst-case scenario (Njå et al., 2022). Tunnel fire events are especially high-risk operations, requiring efficient decision-making under major uncertainties and serious time constraints (Bjelland et al., 2021). The tunnels' enclosed environment generates high temperatures and large concentrations of smoke and toxic gases. In single-tube tunnels, the access route for emergency services may be partially blocked, and road users may be trapped in smoke. It may also be unclear what the nature and extent of the fire is, how many casualties and road users are in immediate danger, what the conditions of the escape routes are, and what the scenario development might be, including the behaviour of road users and the performance of the tunnels' safety systems.

Looking at previous tunnel fires (e.g., the Mont Blanc tunnel fire, the Skatestraum tunnel fire, the Brattli tunnel fire), it is easy to portray scenarios that might exceed the fire and rescue services' possibilities to extinguish (NSIA, 2016b; Voeltzel & Dix, 2004). For instance, in the Mont Blanc case, a lorry carrying flour and margarine started to burn approximately 6.5 km inside the tunnel, and the fire spread rapidly to other vehicles carrying combustible loads. The first response unit arrived at the tunnel entrance after 18 minutes and could not even approach the incident scene. It took the fire and rescue services 53 hours to extinguish the fire. Thirty-nine people died, including a fireman who was evacuated out of an emergency shelter.

In the event of tunnel fires, fire ventilation systems are necessary to control smoke flows and create routes for evacuation and firefighting work. The understanding of how fire ventilation strategies may assist road users evacuating from a smoke-filled environment varies amongst fire and rescue services (Bjørnsen et al., 2023; Njå & Svela, 2018). In Norway, the tunnels' emergency response plans for longitudinally ventilated single-tube tunnels are based on a predefined ventilation

strategy. The rationale is to ensure smoke-free access for the firefighting workforce from the side where the most capable fire department is located. However, in situations such as if the fire occurs near the tunnel portal or if road users are exposed to smoke, assessments of the ventilation strategy must be conducted. Although the strategy of starting the fire ventilation in a predefined direction has occasionally proved to inhibit the possibility of safe escape for road users in the tunnel, experience has shown that assessment of the ventilation direction is a key issue, and the fire and rescue services tend to rely on fixed protocols (NSIA, 2013, 2016a).

Let us imagine a scenario: Consider that a fire department is being alerted that an HGV loaded with unknown goods is on fire in a single-tube subsea tunnel with bi-directional traffic. The tunnel is 6 kilometres long, has a gradient of 7% and a response time of about 20 minutes. The road user calling to report the incident states that the HGV driver initiated the necessary actions but was unable to extinguish the fire and evacuated the tunnel. The fire's location is identified at approximately 3.5 kilometres towards the tunnel's opening on the north side. As soon as the Road Traffic Centre (RTC) is notified, the tunnel is closed in accordance with the emergency response plan and the fire ventilation is activated in the predefined direction (towards north). This means that the smoke from the fire flows 2.5 kilometres towards the tunnel's opening on the north side and fills the tunnel with smoke at a rate of 8 m/s. There is further information that there is traffic jam, four vehicles are parked approximately 200 metres downstream of the incident scene, and several road users have been seen walking towards the north side. The major concern is people exposed to smoke and evacuating to the north, the fire energy released by the unknown load of the HGV and the risk of escalation as part of the developing risk scenario.

Not all incidents in road tunnels challenge the fire and rescue services' capacity to tackle the situation. For instance, a burning car can be extinguished easily during the initial development phase of a tunnel fire. However, in situations like the scenario described above, firefighters experience several challenges. The unknown risk related to smoke and heat development constitutes a fundamental threat, and firefighters need to continuously gather information to construct risk assessments through all the phases of the emergency response. As there are many ways to

approach the incident, the tactics and strategies chosen should be carefully considered.

When attempting to cope with the situation, the fire and rescue personnel may encounter key decisions and dilemmas, in which they will have to estimate and balance their personal risk and that of road users. How should the principle of self-rescue be understood and facilitated during the response operation? The higher the thermal output, the stronger the smoke development and the harder it becomes for road users to evacuate the tunnel. One way to avoid this is to prioritize combatting the fire to prevent further smoke development and make the rescue operation "easier". In single-tube tunnels, fire ventilation is a crucial tool for firefighters to provide access to the incident scene and initiate the extinguishing work. Nevertheless, depending on the developing scenario, the predefined ventilation direction may result in inflicting smoke on road users and the spread of fire to other vehicles downstream in the tunnel.

Considering the dynamic nature of tunnel fires, successful emergency response prerequisites involve personnel possessing the competence that enables them to understand the emerging situation and make decisions in "real time" and not just follow a predetermined set of procedures. This usually requires that the relevant level of information about the situation is made available to the personnel at the right time. Decision-making is therefore inseparable from the environment in which the decisions occur (Zsambok & Klein, 1997). Fire and rescue personnel must continuously monitor the situation, understand what is going on, identify changes and anticipate how the situation is likely to develop. However, in tunnel fires, it is difficult to develop and maintain situation awareness, due to the dynamic nature of road users' behaviour, the lack of line of sight to the incident, the obscuration of the scene by smoke and communication challenges between involved parties.

Long distances are also a major challenge during tunnel fire response operations and may cause extraordinarily high physical strain for personnel. Entering a tunnel filled with smoke is a significant problem for firefighters. It is not easy for firefighters to carry smoke diving equipment and hoses over long distances. For example, it makes a huge difference whether an injured person is rescued from a building or has to be carried out over a distance of a hundred metres uphill. Also,

firefighters' air capacity during the rescue operation is limited and their contained breathing apparatus will last for approximately half an hour after entering the tunnel. This implies major uncertainties regarding the firefighting and rescuing performance. Furthermore, firefighters approaching a tunnel with smoke coming out of the portals experience several uncertainties. These may relate to unclear functionality of communication means, access to water supply, the performance of the ventilation systems and the fire's intensity and toxicity. These factors demand critical assessments and set comprehensive requirements of the individual firefighter's knowledge and skills.

2.2 Learning activities in tunnel fire safety work within the Norwegian fire and rescue services

Tunnel fire is introduced as a specific topic in the basic course plan, with the subsequent learning goal: *"The learner shall know about various challenges related to incidents in tunnels"* (NFRA, 2019, p. 14). To achieve this goal, the academy allocates two hours of learning activities, without any guidance on the content or instructional techniques. As learning outcomes, it is expected that the personnel:

- *"Shall know about dangers related to efforts in tunnels (fire, rockslide, explosion, traffic accident, construction phase, PE-foam, etc.);*
- *Shall know about available equipment and how to use it;*
- *Shall know about technical installations in tunnels and how these work, considering ventilation, communication, water, cross-section, and escape routes"* (p. 14).

Following the formal training offered by the NFRA, the local fire department is responsible for ensuring sufficient training and learning activities so that the personnel are able to cope with fires and incidents in tunnels. Since most of the fire departments lack training facilities, training for tunnel fire responses and rescue work is ensured through participation in training exercises in local tunnels. These exercises are mandatory to comply with the requirements in the tunnel fire safety regulation and must be arranged at regular intervals in cooperation with the local road authorities. The exercises should be as realistic as possible

and correspond to the defined scenarios from the risk analysis. Although required by law, the structure and frequency of these training exercises varies significantly. The exercises are usually carried out before commissioning a new tunnel or after major modification work, and participation is arbitrary, depending on who is on duty on the day of the exercise. As a result, it can be several years before a firefighter gets the opportunity to participate in a training exercise.

As a supplement to the formal tunnel fire safety education, the DCP offers a two-day seminar at the Runehamar test tunnel twice a year. The seminar builds on experience from previous incidents in tunnels and various full-scale fire experiments, as well as combining theoretical lectures with a practical demonstration of the fire ventilation system. The target group is fire and rescue personnel at all levels (e.g., firefighters, operational leaders, incident commanders and instructors). The seminar adopts a broad perspective to tunnel fire safety, without addressing the local challenges that fire and rescue personnel encounter in the wide variety of tunnels. In this context, it is also important to note that the fire and rescue services consider the seminar to be extremely expensive, and only a few employees are sent to attend the seminar.

Some fire departments have developed additional tunnel fire safety learning activities to ensure a more systematic development of their personnel's skills and knowledge. The learning activities range from physical training exercises regarding specific tactics and use of tools and equipment to table-top exercises involving hypothetical tunnel fire scenarios in local tunnels. The physical training exercises normally take place outdoors and involve tasks like the use of extinguishing agents to extinguish a car fire, as well as search and rescue techniques using search sticks and marking lights. The exercises end with a debriefing session, where the instructors lead a discussion and encourage personnel to describe their experiences and account for actions taken during the exercise. Further, the table-top exercises seek to drill personnel on important factors they must have knowledge of before determining tactics and strategies to approach the incident, for instance, the tunnel's geometry and safety design, location of the fire, the direction of the airflow, number of road users and vehicles inside the tunnel, fire energy and hazardous materials.

3 Theoretical framework for workplace learning and competence

The previous chapter showed that tunnel fires are complex response operations, and that workplace learning is an inherent part of fire and rescue personnel's competence development. The theoretical framework is essential for establishing how to approach this study's major issue with the subsequent research questions. The papers presented in Part II of this thesis contain relatively short sections that describe relevant theoretical frameworks. This chapter elaborates upon the concepts and frameworks that constitute the basis of the studies presented in this thesis.

This chapter aims to clarify what is meant by workplace learning in the context of fire and rescue services and how fire and rescue personnel acquire knowledge and skills to become competent practitioners and ensure that incidents in tunnels are handled adequately. It has been suggested that understanding the complex and multifaceted field of workplace learning and competence requires a broad scientific framework (Braut & Njå, 2009; Illeris, 2010, 2011; Njå & Braut, 2010; Sommer et al., 2013). This chapter brings together an understanding of learning and competence that recognizes cognitive constructivist and socio-cultural aspects as complementary. Additionally, this chapter includes elements from a systems theory and design science approach for two reasons: First, Nancy Leveson's (2011) systems theory approach provides a theoretical framework to understand how the tunnel fire safety learning system may be modelled to ensure safety. Second, design science offers an empirical foundation that provides insight into how designers should think to assist the design and implementation of learning activities (March & Smith, 1995).

3.1 Systems theory as a premise to facilitate learning and competence

The complexity of emergency response operations in road tunnels directs the attention towards how to facilitate learning and competence in tunnel fire safety within the fire and rescue services. Leveson (2011) describes

complexity as intellectual unmanageability and claims that the traditional safety approaches have become inadequate to manage complex socio-technical systems. The diversity of actors and components involved in the design and operation of the tunnel fire safety learning system comprises not only organizational and managerial aspects but also technical systems. The interaction between social and technical components gives the tunnel fire safety learning system the character of being a complex socio-technical system (Leveson, 2011; Rasmussen, 1997). Focusing on systems taken as a whole, Leveson (2004, 2011) proposes a systems theory approach to safety as a way of dealing with complexity. The underlying assumption is that learning and competence in tunnel fire safety can be treated adequately only by taking into account all aspects related to the social and technical aspects of the system.

In this view, accidents are seen as products of inadequate control actions or enforcement of safety-related constraints on the behaviour of the components in the system (Leveson, 2004, 2011). Learning and competence in tunnel fire safety becomes a control problem that needs to be managed through the enforcement of safety constraints on the system's components' behaviour and their interactions. *"Constraints represent acceptable ways the system or organization can achieve the mission goals"* (Leveson, 2011, p. 11) (i.e., adequate emergency responses in tunnel fires). Situations leading to losses and injuries arise because the safety-related constraints were inappropriate or not successfully enforced. Controlling learning processes and ensuring sufficient competence within the tunnel fire safety learning system becomes a central part of the tunnel fire safety work. From a feedback control point of view, competence requirements for fire and rescue personnel must be specified and analyses of learning activities must be conducted to provide information about the current state of the system and the functionality of the safety constraints (Bjørnsen & Njå, 2019). In light of the feedback received, controllers may change and adapt the controlled actions to bring the state of the system towards the desired goal. Monitoring learning processes within the fire and rescue services is a challenging task. The current approaches and tools used to develop and evaluate learning activities are inaccurate and unclear. Thus, it is paramount to understand learning processes and which principles,

models and tools are best suited to design learning activities and develop fire and rescue personnel's competence in tunnel fire safety.

3.2 Perspectives on workplace learning

Theories of workplace learning are individually focused, placing the individual at the centre of learning in organizations (Illeris, 2004, 2010). Such theories are valuable because they are directly related to the situations and challenges that occur in a particular working environment and therefore better suited to meet the relevant issues of competence development amongst workers than learning that occurs in formal educational institutions (Illeris, 2010). Workplace learning may be seen as all learning (i.e., formal and informal learning activities) that takes place either directly at the fire department or in other arenas that relate to the development of fire and rescue personnel's occupational capabilities. Further, it covers not only those situations where the personnel involve themselves deliberately to acquire knowledge and skills but also those situations where they acquire knowledge and skills either without conscious effort or through the 'normal' process of development.

Researchers on workplace learning have found it difficult to reach a consensus about a single theoretical framework able to capture all aspects of the concept. For instance, the behaviourist tradition seeks to explain learning in terms of observable modifications to bodily movements by external stimuli. The main issue here is not to understand how ideas and conceptions arise but, rather, to understand under which circumstances the individual acquires new behaviour (Phillips & Soltis, 2009). Thorndike's work on *operant conditioning* demonstrated that any behaviour that is followed by pleasant consequences is likely to be repeated, and any behaviour followed by unpleasant consequences is likely to be stopped. Within this understanding, the implementation of positive reinforcement is assumed to speed up the learning process.

Skinner (1965) developed further the theoretical basis of positive reinforcement and claimed that the consequence of a response determines the probability of it being repeated. He believed that, if the consequence of a certain action is rewarding, the individual will learn to repeat that action if he/she is exposed to the same stimuli again. If fire and rescue

personnel experience positive outcomes from a learning situation or a response to an incident, they will learn that this behaviour is beneficial, and the behaviour is likely to be repeated in new situations with similar cues. For instance, during training exercises, the use of fire blankets proved to be an efficient method to isolate vehicle fires and control smoke development. In the Hundvåg tunnel fire, a tactical priority for the first rescue unit at the incident site was to combat the vehicle fire by using a fire blanket.

Applying this perspective to workplace learning requires that the occupational tasks are specifiable as series of behaviours that can be minutely codified and employees trained to perform the tasks correctly (Hager, 2011). As a result, learning can be acquired in training rooms and prior to entering the workplace. The emphasis is on facilitating the appropriate stimuli and reinforcements, so that prospective workers learn the desired behaviour. Nevertheless, a major implication is that behaviours that form adequate responses to tunnel fires are not minutely codifiable behaviours as required by this theory but demand behaviours as results of comprehensive assessments derived from situational specific cues.

The limitations of behaviourism's ability to account for workplace learning has inspired cognitive theories advocating unobservable mental features (e.g., thinking, reflection, understanding) and socio-cultural theories elevating the social aspects of learning. Argyris and Schön (1996) made a major contribution to workplace learning and introduced the concept of *single- and double-loop learning*. Single-loop learning refers to *"instrumental learning that changes strategies and ways that leave the values of a theory of action unchanged, while double-loop learning concerns learning that results in change in the value of a theory-in-use, as well as in its strategies and assumptions"* (p. 20). To account further for workplace learning, Schön (1991) weighted the notions of *reflection-in-action* and *reflection-on-action*. Reflection-in-action is associated with the experience of a surprise and is the process that allows professionals to reflect and reshape an activity while working. Reflection-on-action involves reflecting on an experience after its occurrence and refers to professionals exploring what happened in the specific situation, why they acted as they did and whether they could have acted differently.

Alternative understanding of workplace learning advocates learning as a social process that takes place in interaction between individuals, for instance in various *communities of practice* (Lave & Wenger, 1991). Workplace learning is seen as situated in a specific context and takes place through the process of participation in work-related activities.

The complexity that governs the nature of workplace learning has led several researchers (Beckett & Hager, 2002; Hager, 2004; Sfard, 1998) to point to two major trends as influential for our understanding of the concept: *the cognitive constructivist approach to learning* (i.e., learning as acquisition of knowledge and skills) and *the socio-cultural approach to learning* (i.e., learning as participation in social systems). As suggested by Sfard (1998), one perspective alone is not enough to fully understand how workplace learning occurs and *"we can live neither with nor without either of them"* (p. 10). Since both perspectives have clear advantages to explain workplace learning, she suggests that an adequate combination of them *"would bring to the fore the advantages of each of them, while keeping their respective drawbacks at bay"* (p. 11). Some researchers have demonstrated that each of these two approaches has something to offer that the other cannot provide, and that giving full theoretical exclusivity to one would hamper fully understanding how individuals learn in workplace settings (Braut & Njå, 2009; Illeris, 2010, 2011; Sommer et al., 2013).

3.2.1 An integrated model of workplace learning

In Scandinavia, one of the most prominent models of workplace learning is presented by Knud Illeris (2004, 2010, 2011), who integrates cognitive constructivist and the socio-cultural aspects of learning. He argues that all human learning consists of two different types of processes at once: *an internal psychological process of acquisition* in which new stimuli and experiences are linked to the results of prior learning and *an external interaction process* between the individual and the social, cultural and material environment. When put together, these two processes form the three dimensions of learning: *the content*, *the incentive* and *the environment*. Figure 1 depicts Illeris' (2007) model of the fundamental process of learning, which is a good starting point for describing essential aspects of learning within the fire and rescue services.

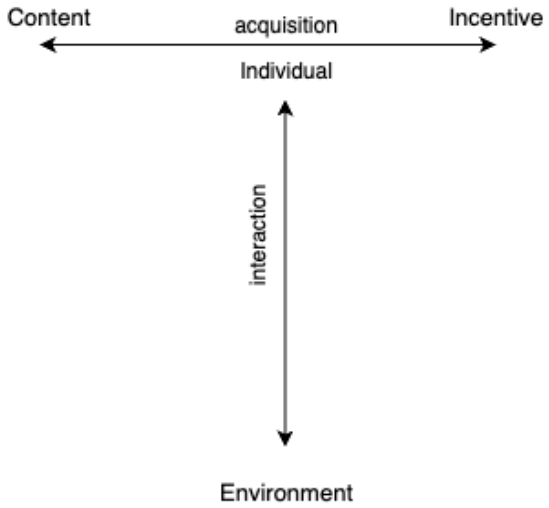

Figure 1: The fundamental process of learning (Illeris, 2007)

The external interaction process illustrated by the vertical double arrow connects the individual and the learning environment. For instance, this might be the individual firefighter confronting a tunnel fire or a learning situation (e.g., theoretical lecture, table-top exercise, physical role-play exercise). In this process, the criteria for learning are situated in the fire department's arena of social interaction (e.g., artefacts, procedures, practices, gatherings, responses to incidents, evaluation of responses). Further, the horizontal double arrow depicts the internal psychological process of acquisition, which links impulses and stimuli from the interaction with results from previous learning and thereby forms the learning outcome. In this process, the criteria for learning are based on the content of what is being learned (e.g., knowledge, skills, attitudes) and the incentive aspect that provides the necessary mental energy for the learning process (e.g., motivation, emotions, volition) (Illeris, 2003).

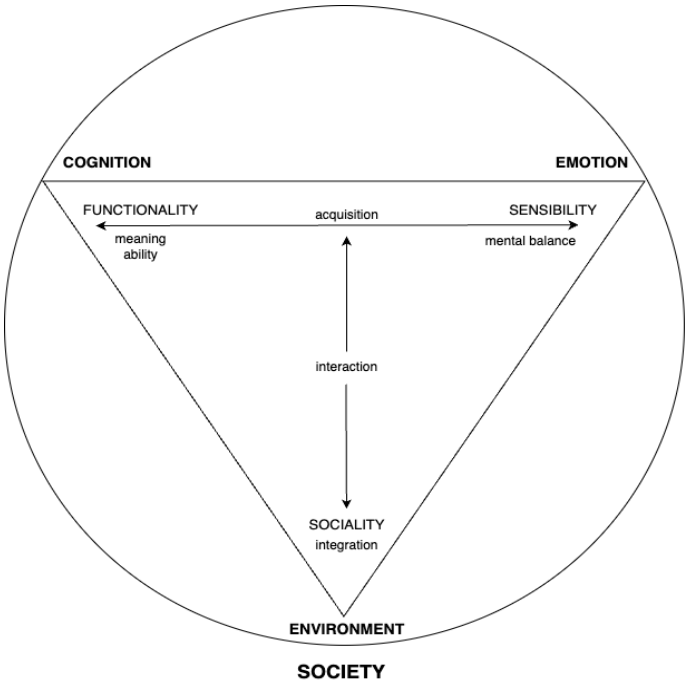

Figure 2: The process and dimensions of learning (Illeris, 2003)

Illeris (2003) further elaborates that the cognitive function of learning is the dimension of content (see Figures 1 and 2). Its purpose is to construct *meaning* and the ability to deal with practical challenges so that learners develop an overall personal *functionality*. The emotional function is the incentive dimension and represents the driving force which helps learners to mobilize energy and engage in the learning process. Its aim is to ensure *mental balance* and develop a personal *sensibility* within learners. Individual learning is always situated in a social context or a certain learning environment. The environment dimension relates to external interaction and may take place as participation, action, communication and cooperation. The intention is to help the personal *integration* of learners in communities of practice and develop their *sociality*. Lastly, the learning process is embedded in a societally situated context that establishes the premises for interaction.

Illeris' dimensions of learning are all highly relevant for understanding learning within the fire and rescue services. For instance, fire and rescue

personnel need to meet emergency responses in tunnels in a functional way. They must know which tactics and strategies to implement, be familiar with response practices and how to perform them satisfactorily. Thus, the content of learning must provide opportunities for equipping the personnel with knowledge and skills to ensure that incidents in tunnels are handled adequately. For instance, tunnel fire responses require knowledge of the following: safety designs in tunnels, risk and uncertainties faced in emergency responses and how different phases of the response should be approached. Likewise, the learning outcome depends on how the content is experienced, how committed the personnel are to learning and what sorts of feelings and motivations are involved. If learning is driven by desire and interest and the content is experienced as meaningful, the personnel will be more inclined to apply the acquired knowledge and skills to situations that resemble the learning situation. Conversely, learning outcomes are more likely to fade or be forgotten if the personnel experience lack of interest or reluctance to learn.

Learning within the fire and rescue services is also strongly influenced by the social relations existing in the fire department and the interactions between colleagues, as well as the way in which the personnel involve themselves in work-related activities (Bjørnsen & Njå, 2023). In this process, specific kinds of knowledge developed through the fire department's history (i.e., procedures, practices, working methods, evaluation reports, artefacts) are mediated and made available to the personnel. A part of the learning process is also constituted by the interaction between the cultural and social background of the personnel and the traditions, norms and values of the fire department where the learning takes place. Illeris (2011) argues that, if learning is to obtain the qualities of competence development, learning activities must develop individuals' functionality, sensitivity and sociality.

Cognitive constructivist aspects of workplace learning

Illeris' (2010) understanding of the internal psychological process of acquisition builds on Jean Piaget's concept of learning and recognizes the individual as actively building and constructing his/her own cognitive structures. Within this perspective, learning is understood as *an active process in which learners construct meaning by linking new ideas with*

their existing knowledge (Naylor & Keogh, 1999, p. 93). These cognitive structures or schema are patterns of mental action that the individual uses to organize knowledge, guide mental processes and behaviour, and comprise all the knowledge, experience and way of thinking (e.g., the ability to reason, connect ideas and solve problems). New accumulated knowledge and information is processed based on how it fits into existing cognitive structures, and, on this basis, it is possible to differentiate between four types of learning: *cumulative learning*, *assimilative learning*, *accommodative learning* and *transformative learning* (Illeris, 2003, 2010).

Cumulative learning is isolated in terms of content and occurs when a scheme or pattern is established (Illeris, 2003, 2010). The learning outcomes are characterized by a type of automation and can only be used in situations similar to the learning situation. Assimilative learning involves the interpretation of events in terms of existing cognitive structures and occurs when the individual faces unknown situations and attempts to understand these situations by linking the new element to a scheme or pattern that is already established. The learning outcomes are linked to the scheme or pattern in question in such a manner that they are relatively easy to recall and apply in situations within the area in question. However, when existing schemas are insufficient and the cognitive structures are incapable of dealing with new experiences, individuals will accommodate existing schemas. Accommodative learning is the process of restructuring existing schemas to provide better explanations for new experiences that better fit reality. The learning outcomes can be recalled and used within a broad range of relevant situations. Lastly, transformative learning results from a crisis-like situation and involves the decomposition of several schemas in a coherent process and their restructuring into a new coherent understanding through critical reflection (Mezirow, 2009). Based on prior experience and creativity, elements that present themselves as important are assessed and combined to produce deep situational understanding (Dreyfus & Dreyfus, 1986).

These four types of learning are activated in different situations and imply different levels of learning outcomes. The outcomes span from the individual's ability to adapt existing knowledge and skills to the ability to use past experiences in new ways and produce radical change in

knowledge and skills, in order to gain new knowledge with which to act. For instance, when fire and rescue personnel are confronted with a new situation and must respond to an incident or fire in a tunnel, the decisions and response actions will be based on their background knowledge and results from previous learning. At times, the personnel may experience their background knowledge and experience as being inadequate to understand the situation and respond effectively. In such situations, they will search for new knowledge and try to accommodate previous knowledge and experience to reconstitute efficient decisions and response actions. In situations that have profound significance for the personnel, for example if their own safety or road users' safety is at stake, critical reflections may be triggered to make sense of the situation and deal with challenges in the environment. Table-top and role-play exercises addressing actual risks in local tunnel contexts are useful pedagogical tools for stimulating personnel to assess the key assumptions on which their decisions and response actions are constructed and to correct distortions in their understandings and problem-solving abilities (Bjørnsen & Njå, 2023).

Illeris (2009b) claims that competence development requires aspects of accommodative and transformative learning to be included to a considerable extent in learning activities. To achieve learning and enhance fire and rescue personnel's competence in tunnel fire safety, the fire and rescue services must design learning activities that involve problem-solving, investigations, creativity and practice of various types.

Socio-cultural aspects of workplace learning

Another theory that has been of relevance for workplace learning is the socio-cultural understanding of learning (Beckett & Hager, 2002; Hager, 2004). An argument that underpins this position is that it is difficult to understand an individual's cognitive reasoning without observing its interaction in a context, within a culture. Within this perspective, participation in social systems and social relations between people are central sources for learning (Lave & Wenger, 1991; Sfard, 1998). Learning outcomes materialize as changes in both the learner and the environment, rather than being simply a change in the properties of the learner (Hager, 2004). Since acquisition of knowledge changes both the learner and the environment, workplace learning is rooted in activities

and experiences which are inherently contextual. Knowledge is not located in individuals' minds but is created by negotiations of meaning of words, actions, situations and material artefacts (Gherardi et al., 1998). *"To know is to be capable of participating with the requisite competence in the complex web of relationships among people and activities"* (p. 274). Workplace learning becomes a practical accomplishment, whose purpose is to identify what to do in a particular situation, when and how to do it using specific practices and artefacts, and how to provide a satisfactory explanation of why it was done in such manner.

The external interaction processes illustrated by Illeris' model of learning (see Figure 1 and 2) are associated with Lave and Wenger's (1991) view that all learning takes place in a specific situation or context. Rather than describing learning as acquisition of knowledge and questioning what kinds of cognitive structures are involved, they situate learning in particular forms of social participation and examine the kinds of social engagements that provide the context for learning to occur. The concepts of *communities of practice* and *legitimate peripheral participation* are introduced to describe the learning process that novices go through to gain knowledge and skills that enable them to become full members of a community (i.e., the fire department). Mastery of knowledge and skills requires newcomers to a workplace to engage in the cultural practices of the community and interact with more experienced colleagues. For instance, in the initial phase, learning within the fire and rescue services takes place as a period of apprenticeship. Although new firefighters attend the formal learning activities offered by the NFRA, most of their knowledge and skills are acquired through processes of social interaction at the local fire department.

Lave and Wenger propose that *"a community of practice is a set of relations among persons, activity, and world, over time and in relation to other tangential and overlapping communities of practice"* (p. 98). Thus, a community of practice is not only a storage place for the skills and knowledge entailed in the community's activity (i.e., tunnel fire safety and rescue work) but, rather, *"an intrinsic condition for the existence of knowledge, not least because it provides the interpretive support necessary for making sense of its heritage"* (p. 98). Furthermore, Wenger

(1998) maintains that in order for practice to generate coherence within a community, a combination of *mutual engagement*, *joint enterprise* and *shared repertoire* must be present (see Figure 3).

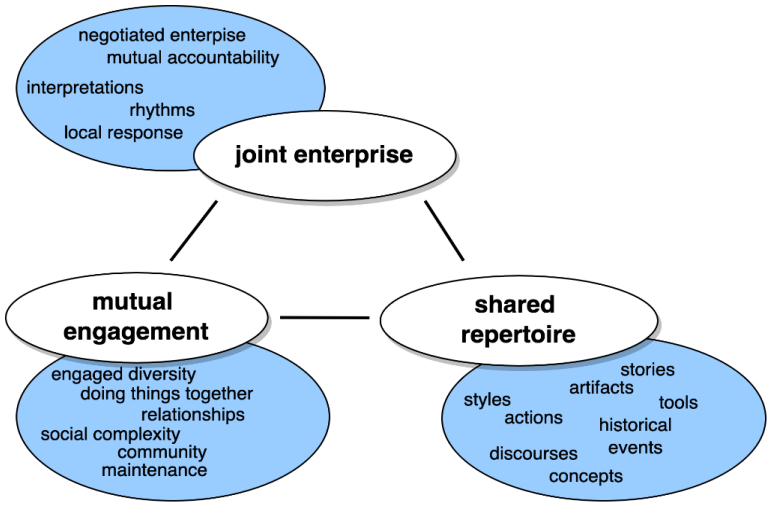

Figure 3: Dimensions of practice as the property of a community (Wenger, 1998)

Mutual engagement suggests that practice does not exist in the abstract but is conceived, as members of a community engage in actions whose meanings they negotiate in interaction with one another. Engagement is crucial to negotiating meaning and fostering a deeper and more critical thinking amongst learners about the norms and power structures that dominate in the community (Deringer, 2017; Wenger, 1998). *Joint enterprise* is the result of a collective process of negotiation in which members become engaged and work together towards a common goal. The enterprise is joint because meanings and understandings are collectively negotiated and not because all members agree with everything. S*hared repertoire* refers to the common resources that members of a community utilize to negotiate meaning and facilitate learning (Wenger, 1998). Hence, tunnel fire response practices evolve as shared experiences of learning. In this sense, learning experiences are not just routines, procedures, tools and working methods that the fire department has produced and incorporated in its practice over time but also research and investigation reports of previous tunnel fires.

Lave and Wenger (1991) view the concept of legitimate peripheral participation as a process characterized by social structures and social relations. *"Legitimate peripheral participation provides a way to speak about the relations between newcomers and old-timers, and about activities, identities, artefacts, and communities of knowledge and practice. It concerns the process by which newcomers become part of a community of practice"* (p. 29). Within a community of practice, a newcomer starts on a learning path where he/she can move from being a legitimate peripheral participant to a full member and skilled professional practitioner. Gradually, through mentoring from more experienced members, the newcomer can internalize the community's values and become a legitimate member of the community of practice. To open up practices, it is paramount that the members get access to mutual engagement with the community members, their actions and negotiations of the enterprise, and the repertoire utilized (Wenger, 1998).

Fire and rescue personnel entering the workplace will become members of the firefighting team by being introduced peripherally to the cultural knowledge and practices of the fire department. Through interaction with more experienced colleagues (i.e., mentors), they socialize and learn the cultural knowledge and practices residing in the fire department and the values internalized in knowledge and practice. The knowledge and practices are mainly generated from emergency responses and training situations and therefore more or less a result of what the involved personnel consider meaningful to share. In this way, the prevailing tactics and strategies adopted during responses to incidents in tunnels are, mostly, a result of traditions, values and social norms developed in the fire department.

It is important to note that the key shared values, norms and traditions that perpetuate in the fire department may not all necessarily be positive and sometimes may result in negative behaviours and attitudes towards learning. For instance, debates and criticism addressing alternative ways to behave and approach tunnel fire responses may be interpreted negatively by the personnel and inhibit their learning. However, the values, norms and traditions (i.e., cultural knowledge and practices) are dynamic and may be renegotiated through dialogue and interaction between new firefighters and existing members of the firefighting team.

The socio-cultural aspects of workplace learning focus on learning as significantly influenced by the context in which learning occurs. An underlying assumption is that the context of learning is socially constructed and that all knowledge is cultural knowledge situated in a social context (Eraut, 2004a). This implies that knowledge has possibly different interpretations across different communities and cultural groups. It is therefore important to reflect on who has the knowledge, who was involved in the construction of knowledge and how the current knowledge is positioned in relation to other knowledge. Within the context of fire and rescue services, tunnel fire response tactics and strategies are reflections of the structure, management and values of the fire department. They are results from a social system that delivers purpose, goals and decision criteria. Without understanding the conventional explanations and the assumptions on which the fire department develops its tunnel fire response practices, it is not possible to completely understand why inadequate situations occur and how to effectively prevent unwanted situations.

Both the cognitive constructivist approach and the socio-cultural approach provide reasonable explanations of learning within the fire and rescue services. However, the two approaches have been criticized for seeing learning primarily as a process that transmits and preserves culture and knowledge, having little to say about transformation and creation of culture and knowledge within the workplace (Engeström, 2014). A main argument is that the two approaches assume that knowledge and skills that individuals acquire through workplace activities and practices are stable and well defined (Engeström, 2001). Engeström claims that, through collective activities, individuals also construct new knowledge and implement this in workplace practice and activities.

3.2.2 Experiential and workplace learning

Another essential model that has been a main source of inspiration to understand workplace learning is David Kolb's (1984) experiential learning cycle. The experiential learning cycle illustrates the range of theoretical models, while at the same time describing important features of learning within the fire and rescue services. For instance, essential for

the learning process are the experiential actions that fire and rescue personnel engage in and the associations these actions produce. Learning is defined *"as the process whereby knowledge is created through the transformation of experience"* (p. 41). The model illustrated in Figure 4 theorizes that learning is an ongoing circular process, transforming concrete experiences through reflection, the forming of mental models, and the testing of conclusions. Within this understanding, the process of learning consists of two primary dimensions: i) concrete experiences at one end and abstract conceptualization at the other, and ii) active experimentation at one extreme and reflective observations at the other. The combination of experience, perception, cognition and behaviour provides a holistic integrative learning perspective where learning is conceived as a complex process rather than distinct behavioural outcomes (Kolb, 1984). To achieve learning, fire and rescue personnel must be capable of involving themselves fully and actively in new experiences, reflecting on the experiences from different perspectives, creating concepts that integrate their observations into valid theoretical constructs, and then using the theories to make decisions and solve problems.

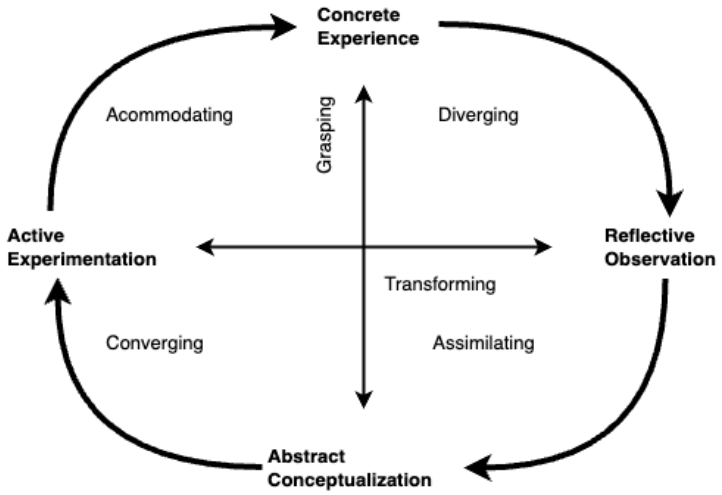

Figure 4: Experiential learning cycle (Kolb, 1984)

One important source that Kolb refers to is the work of John Dewey. Within the modern understanding of experiential learning, John Dewey

has had one of the most important voices on matters of experience. By placing a great deal of importance on the value of shared, interactive experience, for Dewey, thinking and knowledge acquisition cannot be separated from the world in which we live (Biesta & Burbules, 2003; Roberts, 2012). *"It is in the interaction between the two, and how the two revise each other, that brings about new awareness and learning"* (Roberts, 2012, p. 51). The social construction of experience (e.g., tunnel fire response practices) is assumed to be realized between thinking and doing, in a continuous interaction between the individuals and the world (Hohr, 2013; Roberts, 2012). Through this interaction and continuous efforts to maintain a dynamic balance with the world, individuals develop patterns of actions (Biesta & Burbules, 2003). Dewey believed that the acquisition of knowledge and possible ways to respond and interact with the world is one or more cycles of trial and error in which individuals undergo the consequences of their doings and try to adjust themselves accordingly. As a result, individuals both change the world and are changed by it (Rodgers, 2002). Dewey argued that learning from experience occurs when learners attempt to solve real problems.

Problem-solving is inherently contextual, grounded in the idea that universal rules or foundations that can be applied to all types of situations are inadequate (Roberts, 2012). However, this requires *"both action in the form of doing in the world and reflection in the form of cumulative and contingent knowledge gained over time"* (p. 54). Hence, experiences alone obtained through participation in tunnel fire events, training exercises or learning activities are not enough for fire and rescue personnel to achieve learning. What is crucial is their ability to perceive, create meaning and then act on these experiences. To achieve learning, personnel need to reflect on actual challenges and problems that may arise in tunnel fire response and then, through experimentation, find solutions to solve the specific problems.

3.3 Understanding learning within the fire and rescue services

To further illustrate how the theoretical framework has guided my understanding of learning within the fire and rescue services, I have adopted a model for learning in emergency response work which was

developed by Sommer et al. (2013). The work initially started in 2007 at the University of Stavanger as part of the ACCILERN research project (see Braut & Njå, 2009; Njå et al., 2010; 2012). The model depicted in Figure 5 builds on Illeris' (2003, 2007) and Kolb's (1984) model of learning and combines cognitive constructivist aspects of workplace learning and socio-cultural aspects of workplace learning. Focusing on the individual's need to learn, the model places the individual as the starting point to understand learning. The model pays attention to the contextual aspects as well as the skills, knowledge and problem-solving abilities that fire and rescue personnel must learn to deal with work-related activities and challenges (Sommer, 2015; Sommer et al., 2013). Theories of learning are often centred on processes where an individual acquires specific knowledge or skills in such a way that a subsequent, relatively lasting change in behaviour is noticed (Engeström, 2001). Within the context of fire and rescue services, this is a rather narrow perspective. For this thesis, learning is understood as the *"process related to establishing new knowledge aiming to implement changes to, gaining deeper comprehension of and/or confirming the basis for, current apprehensions and practices"* (Njå & Braut, 2010, p. 43).

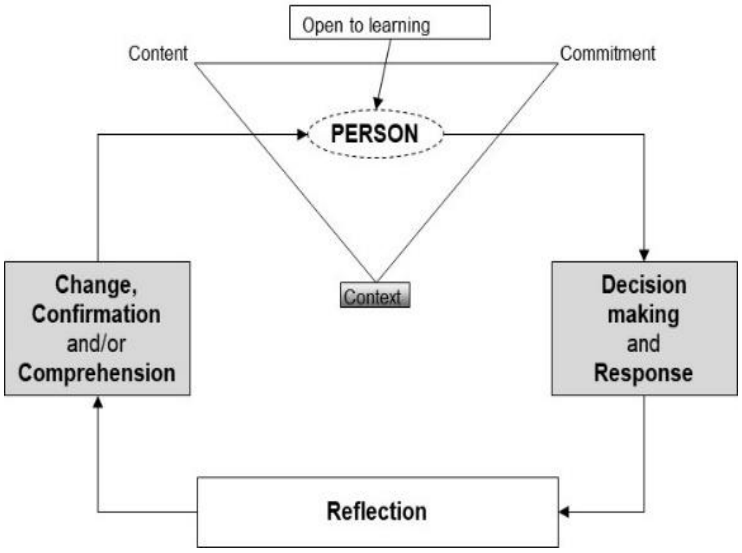

Figure 5: Learning in emergency response work (Sommer et al., 2013)

The model sees learning as a continuous and circular process, involving six interrelated concepts: *content*, *context*, *commitment*, *decision-making and response*, *reflection* and the outcome of learning expressed as *change*, *confirmation* and/or *comprehension* (Sommer et al., 2013). Sfard (1998) claims that the very essence of learning is related to *"our ability to prepare ourselves today to deal with new situations we are going to encounter tomorrow"* (p. 9). Competent practitioners should therefore be able to repeat what can (and should) be repeated while changing what needs to be changed. Traditionally, learning outcomes have been understood in terms of directly observable features and explained as *changes* in structure, behaviour, cognition, processes or organizations (see Argyris & Schön, 1996; Illeris, 2007). This also applies to learning within the fire and rescue services. It follows the idea that fire and rescue personnel learn when they develop new knowledge and skills and change the way they behave, react and respond to emergency situations in tunnels.

However, learning outcomes may also contain features which are less observable but equally important as concrete changes in behaviour. Learning involves *confirmation* of existing knowledge and practices and *comprehension* of knowledge, established practices and working methods (Braut & Njå, 2009; Sommer, 2015; Sommer et al., 2013). Confirmation is experienced as a kind of positive reinforcement, which has been acknowledged as an essential aspect of learning (Skinner, 1965). If fire and rescue personnel experience their working methods and response practices as being successful, this will act to strengthen the behaviour and encourage them to repeat this behaviour in situations with similar cues. Additionally, new insights may emerge from reflections and assist the personnel to confirm their existing knowledge. In our study, collective discussions during learning activities about how to approach emergency situations in tunnels were highly valuable to confirm that the situation was understood correctly and that right choices of actions were prioritized (Bjørnsen & Njå, 2023). Comprehension is achieved when the personnel gain a deeper understanding of the strengths and weaknesses of the current practices and why their working methods and behaviours are appropriate or not. Our study showed that the more the personnel knew about emergency response situations in tunnels, the more they understood the mechanisms influencing the

outcome of the response and the better prepared they felt to face potential incidents.

Reflection is the processing phase, in which individuals consciously think about a concrete experience, assess what happened and evaluate the response (Boud et al., 1996; Brookfield, 1998). For the individual firefighter to learn from learning activities or emergency response situations, he/she needs to reflect upon the experienced stimuli and inputs. Experience alone is not enough, and reflection is needed prior to the experience, during the experience and after the experience (Boud et al., 1996). The role of reflection is to make meaning of the experience: that is, to construct relationships amongst the elements of the experience, between the experience and the knowledge that the individual possesses, and between existing knowledge and the knowledge generated by others (Rodgers, 2002). This requires individuals to be able to describe their experience, examine the attitudes and emotions that might influence their understanding and make sense of new ideas and information. However, although individuals can construct meaning in isolation, interpretation can be fuller and more complex when produced in a community. Within the fire and rescue services, experience may be acquired through formal learning activities (e.g., educational programmes, training exercises, courses, lectures), or it could be of a more informal character (e.g., responses to incidents, discussions with colleagues, storytelling). Fire and rescue personnel must be able to examine their practices, seek the advice of other colleagues and draw on accumulated knowledge, to better understand their way of doing things, sharpen their judgement, and adapt practices to new knowledge and ideas.

Decision-making and response relate to fire and rescue personnel's performance in real and training situations (Sommer et al., 2013). Decision-making within the context of fire and rescue services comprises activities such as determining goals and needs, scanning options, imagining consequences, conducting trade-offs and predicting obstacles to implementation (Klein, 2015). During training exercises and response to incidents, fire and rescue personnel engage in different types of behaviour and actions which form the outcome of the situation. Dewey argued that, when people solve problems, they do so in an analytical and rational way that follows an orderly sequence of phases (Biesta &

Burbules, 2003). This idea corresponds to normative models of decision-making that typically point out three key phases: situation assessment, plan formulation and plan execution (Lipshitz & Bar-Ilan, 1996; van den Heuvel et al., 2014). To assess the situation and assist in the selection of an appropriate course of action, fire and rescue personnel must gather information that is relevant to the incident. This will help the identification of problems and generate possible solutions and the selection of an appropriate course of action. Subsequently, the personnel must identify objectives and develop a tactical plan whereby suitable actions are selected and implemented.

Equally important are the stimuli situations, the concrete experiences, the taught materials, the learning environment and the involvement of learners. Learning is formed by the individual being placed between elements of *content*, *context* and *commitment* (Sommer et al., 2013). Learning requires that those who are about to learn direct their attention towards something (Levy, 1966). This something is the *content* of what is being learned and must be experienced as relevant, to motivate fire and rescue personnel and improve their problem-solving abilities and performance during responses to incidents in tunnels. For the content to be useful and build up the ability to cope adequately with incidents, it must cover characteristics of the situations that the personnel will meet in real-life settings (e.g., fire and smoke development, decision-making and allocation of responsibilities, human behaviour in crisis, extinguishing methods, risk related to response operations, search methods, coping with uncertainties) (Bjørnsen et al., 2020).

The *context* in which learning takes place and the possibilities for learners' *commitment* to learning will also influence what is learned and how much learning occurs (Sommer et al., 2013). The importance of understanding learning as situated in a context with activities and interactions focused on sustaining workplace practices through participation is emphasized by the socio-cultural theories (Billett, 2004; Lave & Wenger, 1991; Wenger, 1998). For instance, different kinds of settings (e.g., practice in realistic training facilities, classroom instruction, participation in emergency response operations) will provide different kinds of experiences that can make different contributions to fire and rescue personnel's knowledge and skills development. Learning

also requires collaboration with other colleagues, and the individual firefighter's ability to perform effectively depends on the performance of the firefighting team. Thus, relationships, trust and social climate at the workplace become decisive for the individual's possibilities to learn (Eraut, 2004b; Sveiby & Simons, 2002). Lastly, effective learning must be built on processes that are conceived as meaningful by learners, and individuals' *commitment* to what is learned determines how they participate in and what they learn from experiences (Sommer et al., 2013). Commitment refers to involvement in learning activities and may be manifested as active participation and interaction in work-related activities and/or as a cognitive function where the mental energy required to drive the learning process is mobilized.

Sommer at al.'s (2013) learning model should be understood as a way of providing an overview while at the same time indicating what may be considered the most significant elements that apply to learning within the fire and rescue services. For fire and rescue personnel, the workplace represents one of the most viable arenas to learn and develop vocational expertise. The ability to understand the process of learning is, to me, a principal competence, one which distinguishes the successful from the less successful fire department and, hence, how emergency situations in tunnels are handled. Consequently, it is important to address the issue of competence within the fire and rescue services because the end goal of workplace learning – to ensure high-level performance during emergency situations in tunnels – occurs in relation to competence development amongst the personnel.

3.4 Perspectives on competence

Illeris uses several definitions of competence, mainly focused on individuals' adequacy to function effectively in the world. For instance, he refers to Hermann, who defines competence as *"the ability and preparedness to meet a challenge through action, in which the challenge is unexpected and contextual (dependent on the context and the environment in which it occurs), not being a routine task but new, and not being reflected in specific success criteria, but subject to an infinite number of outcomes"* (in Illeris, 2017, p. 34). Broadly, this definition concerns individuals' ability to deal with relevant but often complex and

unforeseen situations. The allusion to complexity and uncertainty seeks to capture the continuous development in our society which constantly generates new and unknown challenges (i.e., incidents and fires in tunnels).

Illeris also refers to Jørgensen's (1999) definition of competence, which goes beyond individuals' proficiency and performance of skills and also includes attitudes and values. Tunnel fire safety competence within the fire and rescue services may be understood as fire and rescue personnel's ability to satisfactorily approach future and unpredicted situations in tunnels. Further, it also involves their attitudes and values manifested in judgements and choices of action during tunnel fire responses. From a workplace learning perspective, this raises the need to understand what constitutes tunnel fire safety competence within the fire and rescue services so that efficient learning activities and educational programmes may be developed.

Interpretations and understandings of competence vary across different scientific communities. For instance, psychologists tend to be concerned with whether the concept is an attribute of the external performance of an individual in a task-oriented context and whether the observable performance of the individual represents his/her underlying traits or ability (Sternberg & Kolligian Jr, 1990). Management theorists look at the concept by analysing how the overarching goal of an organization can be split down to descriptions of behaviours that provide contributions of occupational performance to achieve the goal (Burgoyne, 1993). Human resource managers have adopted a competence approach that uses the concept as an overall plan for the strategic direction of an organization through the tactics of recruitment, placement, training, assessment, promotion, reward systems and personnel planning. Educationists seek to relate the concept to the idea of work preparation and professional recognition with that of broad education (Bowden & Masters, 1993). This view is a derivation of the development in professional organizations and a response from educational institutions to satisfy the demands of employees (Stoof et al., 2002).

According to Hoffmann (1999), this multitude of interpretations reflects different conceptualizations and, occasionally, leads to confusion amongst those trying to achieve improved work performance. The

different interpretations may be attributed to the diverse epistemological assumptions (Pate et al., 2003).

3.4.1 Behaviourist/cognitivist and constructivist perspectives on competence

The behaviourist/cognitivist perspective, also referred to as the rationalistic perspective, originates from an objectivist epistemology which differentiates between the job and the worker (Pate et al., 2003). Here, competence is seen as constituted by a specific set of attributes, such as the knowledge and skills that workers use to perform a certain occupation (Sandberg, 2000). A widespread assumption is that those who possess a superior set of attributes can execute their job more proficiently than others. For individuals to become professionally capable (i.e., competent), the literature proposes that those attributes comprise domain-specific conceptual, procedural and dispositional capacities (Billett et al., 2018). These capacities are captured in textbooks, occupational standards and requirements for practice and represent the societal expectation of what those practising a particular occupation (i.e., firefighters) need to know, do and value. Furthermore, the attributes are considered context-independent, implying that competence may materialize in a wide range of work activities (i.e., occupations). When competence is viewed as independent of the context in which it occurs, it is regarded as a generalizable body of knowledge, skills and attitudes (Dall'Alba & Sandberg, 1996). For instance, a specific attribute, such as fire and rescue personnel's decision-making skills, is considered to have a fixed meaning in itself; it is regarded as independent of the context in which the decisions occur and thus able to be adopted in different occupations. As a result, advocates of this perspective stipulate that it is possible to compile descriptions of job activities that are independent of the individuals accomplishing the work tasks.

Although this perspective makes major contributions to the interpretation of the concept, the understanding of competence as a set of attributes that are context-independent is criticized for being narrowly focused and problematic for identifying and explaining competence at work (Pate et al., 2003; Sandberg, 2000). More precisely, the set of

attributes does not describe what constitutes competence in accomplishing a job efficiently but, rather, significant prerequisites for performing the job competently. Furthermore, it is claimed that this perspective produces descriptions of competence that are too general and abstract and ignores the complexity of competence in work performance by assuming that all tasks or situations are predetermined.

The constructivist perspective provides an alternative understanding of competence, considering the worker and the work as a single entity arising through the lived experience of work (Pate et al., 2003; Sandberg, 2000). Here, competence is seen not as having an objective structure but, rather, as constituted by the meaning the work takes on for the worker in his/her experience of it (Dall'Alba & Sandberg, 1996). The main idea is that workers cannot meaningfully be separated from their work activities and the situations in which they perform these activities. Schön (1991) made a similar point, stipulating that when individuals encounter their work, they frame and set the problem situations of the work through their experiences of it. Accordingly, the main feature of this perspective rests on a phenomenological base, in which the individual and the world are strongly interrelated through the individual's lived experience of the world (Berger & Luckman, 1966; Giddens, 1984). *"It is through our lived experience of the world that the world takes meaning to us"* (Dall'Alba & Sandberg, 1996, p. 416). By placing the individual's lived experience at the centre to perform a job competently, this perspective overcomes the most significant limitation of the behaviourist/cognitivist perspective in which the meaning of experience is neglected.

In this thesis, I consider the behaviourist/cognitivist and constructivist perspectives as complementary. For instance, fire and rescue personnel's competence is partially viewed as a context-free set of attributes (e.g., domain-specific concepts, procedures and dispositions) that they bring to the job. However, such descriptions cannot capture whether they use these attributes nor how they use them to achieve specific work tasks (i.e., responses to tunnel fires). Thus, defining what constitutes competence in accomplishing a job proficiently is not context-free but, rather, context-dependent and usually developed in particular circumstances of work practice (Billett, 2001; Lave & Wenger, 1991). During response operations in tunnels, clarification of key activities

based on common situational understanding and clear communication of the action plan is a main priority for the firefighting team. However, the complexity of the situation affects the extent to which clarification of key activities may receive central attention. For instance, road users involved in a tunnel fire may not immediately perceive that they are exposed to a serious threat and choose not to evacuate the tunnel while the circumstances still permit a safe egress. This will complicate the situation, in the sense that some road users may need immediate medical assistance. In such situations, the central attention needs to shift from the clarification of key activities to the facilitation of rescue activities as the main priority. Thus, besides the shared understandings of which actions are most suitable during response operations in tunnels, the personnel must also attend to the peculiarities of the situation at hand.

Building upon this theoretical framework, competence is viewed neither as a characteristic of the individual nor as a characteristic of the job (Ellström, 1997). Fire and rescue personnel's competence in tunnel fire safety is therefore not primarily constituted by descriptions of generalizable attributes (i.e., knowledge, skills, attitudes) which are separable from the work in which it occurs. The emphasis is, instead, on relational factors amongst the personnel, the tunnel system and the situation in which they act, and on the competence applied to the specific problems they encounter. Consequently, fire and rescue personnel's competence occurs in the working environment, partly by the knowledge and skills they bring to the job and partly by the characteristics of the job and the situation (e.g., situational specific cues, policy procedures, performance requirements, financial and technical resources) (Bjørnsen et al., 2023). By focusing on the interaction between the personnel and the job, competence is assigned a dynamic character which is negotiated between their capabilities, the requirements of the job and the specific characteristics of the situation. Thus, the analysis of tunnel fire safety competence is founded within the specific domain of firefighters' knowledge, and how they interpret the situation, make judgements and act situationally when confronting hypothetical fire events in tunnels.

3.5 Competence within the fire and rescue services

Competence in the context of fire and rescue services relates to the knowledge and skills that the individual firefighter and the fire department deem necessary to deal satisfactorily with all kinds of emergency situations (Sommer & Njå, 2011). Emergency situations can be described as unplanned, unscheduled, unprecedented and unpleasant to the victims and almost unmanageable events (Rosenthal et al., 2001). During emergency situations in tunnels, the time pressure and the uncertainty involved may be enormous, and the ability to make prompt decisions and respond effectively in a rapidly changing environment is essential. Within the Naturalistic Decision Making (NDM) tradition, uncertainty is related to individuals' cognitive reasoning based on: i) insufficient information, ii) conflicting meanings and values conveyed through available information, and iii) similarity amongst alternatives (i.e., equally attractive or unattractive) (Lipshitz & Strauss, 1997). A general view is that these sources of uncertainties lead to different coping strategies amongst individuals involved in emergency response work.

When seeking to develop fire and rescue personnel's competence regarding coping with future and unknown situations, the challenges and uncertainties that may probably be faced should be considered and included in learning activities. Important tasks in emergency response work concern outlining strategies for hazard mitigation, choosing tactics and performing danger-limitation work effectively (Njå, 1998; Sommer & Njå, 2011). During tunnel fire responses, incident commanders are primarily concerned with outlining appropriate strategies and choosing corresponding tactics, while firefighters' tasks are to perform danger-limitation work successfully. A tunnel fire is a response operation in which the health-related matter of the road users is at the forefront. The fire and its planned and executed response are a catalyst which may worsen or reduce road users' healthcare quality. The firefighting team must deal with uncertainties that are, inter alia, related to lack of historical information, insufficient models of the fire dynamics and victims' behaviour in crisis situations, limited knowledge regarding the heat development and smoke dispersion, etc. Too often, personnel experience difficulties gaining access to the incident scene and acquiring a detailed overview of the situation. In such situations, information

gathering through the tunnels' surveillance equipment assists the personnel to confirm or disconfirm their current beliefs, use the available information to distinguish between different choices of action, find alternatives and outline appropriate response tactics and strategies.

Adequate emergency response to potential tunnel fires is about dealing with the situation in such a way that the consequences of the fire are as small as possible for road users, first responders and other involved groups. According to Njå (1998), the type of competence required to perform adequately during emergency response situations varies with the complexity, the time restrictions and the expected level of interaction between first responders. Since future emergency situations cannot be accurately described in advance, learning and training activities that seek to develop fire and rescue personnel's competence in tunnel fire safety should not train and drill the personnel for a certain type of behaviour in a specific scenario and a well-known environment. The learning activities should be balanced in a way that the personnel are able to apply the acquired knowledge in situations that resemble the training situations. The issue of ensuring high-level performance in emergency response work requires fire and rescue personnel to be able to recognize typical signs of the situation and implement adequate decisions and response actions. Consequently, learning to make adequate decisions is an essential aspect of developing fire and rescue personnel's competence in tunnel fire safety and enhancing the capability of fire and rescue services to cope with potential tunnel fires.

3.5.1 Decision-making and expertise in tunnel fire safety

Common to both minor and major emergency response situations is the need for decision-making under time pressure, circumstantial uncertainty and the necessity to protect human lives. Yates (2003) states that *"a decision is a commitment to a course of action that is intended to yield results that are satisfying for specified individuals"* (p. 24). Accordingly, the following key features may be identified: *action*, *commitment*, *intention*, *satisfying results* and *specified individuals* (Yates & Tschirhart, 2006). Yates' definition further implies that a decision is ultimately about individuals doing something. However, since not all decisions are carried out, a decision relies on individuals' commitment

to act in a particular way. Furthermore, individuals cannot decide accidentally, even though sometimes decisions are made intuitively. The intentional character follows the idea that decision-making is about achieving satisfying outcomes to serve the interest of particular individuals. Within the context of fire and rescue services, decision-making may be seen as a tool to help the personnel to successfully reach the goal of the emergency response (Rake, 2008).

Decision-making skills are particularly critical in high-risk and dynamic work environments (i.e., tunnel fire responses) (Flin et al., 2008). Research on emergency response management agrees that decision-making is a key factor influencing the outcome of the situation (Boin et al., 2005; Burke, 1997; Rake & Njå, 2009). For instance, during response operations in tunnels, incident commanders engage in decision-making for a wide variety of issues. These issues may concern identifying problems, assessing risks, deciding strategies and tactical priorities, assessing resources, developing and communicating action plans, etc. Usually, the nominated incident commander arrives later at the incident scene, and a low-ranking firefighter acts as commander on-scene until the incident commander arrives and takes over command and control. Thus, in the initial phase, it can be quite arbitrary who acts as incident commander and what background and experience he/she possesses for making the appropriate decisions. When attempting to cope with the situation, fire and rescue personnel may confront key decisions where they will have to estimate and prioritize between different strategies and tactical choices, i.e., whether the main priority should be to extinguish the fire or assist rescue activities (Bjørnsen et al., 2023).

In the 1980s, following a series of major incidents, researchers began to study how experts make decisions in their natural environment (Klein, 2008; Lipshitz et al., 2001; Zsambok & Klein, 1997). NDM can be defined as the study of how experts use their experience to make decisions in settings characterized by high uncertainty, insufficient information, ill-defined goals, time pressure, high-stakes tasks and multiple players (Hoffman, 2006; Orasanu & Connolly, 1993; Salas & Klein, 2001). Within this framework, decision-making is explained as a two-way cognitive process which distinguishes between a reflective and intuitive mindset (Evans & Frankish, 2009; Kahneman, 2012).

A central model developed from the NDM approach is the Recognition Primed Decision (RPD) model (Klein, 1993, 2011). The RPD model identifies *situation recognition* and *mental simulation* as two essential phases during decision-making. Experienced decision-makers use their experience to size-up a situation as typical, identify a typical reaction to the situation and evaluate the action by projecting it forward to see if it fits the situation. Incidents and fires in tunnels are dynamic situations characterized by a rapidly changing environment and high values at stake. Hence, fire and rescue personnel involved in tunnel fire responses must execute their tasks in unknown and unpredictable contexts. Their decisions and actions during responses will, to a large degree, depend on how they recognize and perceive the dynamics of the situation. Considering the process of learning depicted by Sommer et al. (2013), the two phases of the RPD's model capture the dimension of decision-making and response and the dimension of reflection and therefore should be a central part of fire and rescue personnel's learning and competence development. For instance, they should be trained to assess critical situational cues in tunnel fire responses and make conscious choices of decisions and responses after reflecting upon various alternatives.

Flin et al. (2008) emphasize situation assessment as a process that leads to situation awareness. Experienced decision-makers are differentiated from novices, based on their ability to assess the situation. The success of a selected response relies on the accuracy of the situational assessment, whereas inadequate decisions and choices of action are more likely to be the result of incorrect assessments. As a result, effective decision-making and effective performance require high levels of situation awareness (Endsley, 2006). According to Endsley (1995), situation awareness is *"the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"* (p. 36).

Endsley's (1995) definition acknowledges the perception of relevant information as the first level of situation awareness. In complex and dynamic environments, novices may have trouble in knowing which information is most critical, and available information may offer different interpretations of the same image. At the second level, situation

awareness requires that individuals comprehend the meaning and implications of what they have perceived. Patterns of information that have been stored in memory provide guidance to recognize and interpret the cues and information sequences. Due to richer mental models gained through experiences, experts find this process to be more automatic than do novices, who will have to spend more time and energy to understand the pattern of cues (Flin et al., 2008). Finally, at the highest level, situation awareness involves the ability to project from current events to predict how the situation is likely to develop. In the event of a tunnel fire, it is essential that fire and rescue personnel possess knowledge and skills (i.e., competence) that enable them to understand the emerging situation. They must be able to perceive relevant cues of the situation, understand the significance of those cues in light of the operational goal and anticipate future states of the situation. The time before road users are engulfed in smoke is crucial, and their competence must include making sense of signals (e.g., fire dynamics, smoke development, road users' behaviour, technical systems) and responding to such signals with a specific type of behaviour (e.g., investigate the situation, start to extinguish the fire, facilitate self-rescue).

Developing tunnel fire safety competence within the fire and rescue services requires feedback that provides information about the performance of the learning activities (Bjørnsen & Njå, 2019). Thus, feedback from experiences and actions accumulated in learning situations are essential corrective mechanisms that should be incorporated into the design of learning activities.

3.6 Design science – a normative approach to developing learning activities

Design science aims to construct models, methods and implementations that are innovative and valuable (March & Smith, 1995). The two major research activities generated by the design process are: *"building* and *evaluating* new artefacts, where *building is the process of constructing an artefact for a specific purpose and evaluation is the process of determining how well the artefact performs"* (p. 254). Principles of design science have been applied in a variety of fields, such as architecture, engineering, education, psychology and fine arts (Cross,

2001). For example, Abrahamsson (2009) has used principles of design science to deal with safety and risk management issues. In the context of this thesis, design science has been used as a normative approach to develop and organize coursework for incident commanders within the fire and rescue services. Hence, a pilot course for incident commanders constitutes the artefact constructed using design science methodology. Design science methodology is introduced with the purpose of: (1) supporting the design of an artefact (i.e., pilot course) to enhance incident commanders' competence in tunnel fire safety, (2) generating methodological instructions for the iterative development and evaluation of the artefact's performance, and (3) providing context-specific knowledge by reflecting on the design experiences. Consequently, a design science approach was adopted to transfer experiences into settings of learning processes.

In the design and development of an artefact, the designer is mainly concerned with *"how things ought to be – how they ought to be in order to attain goals and to function"* (Simon, 1996, p. 4). When designing learning activities to facilitate competence development amongst fire and rescue personnel, the designer must balance different needs and requirements, learning goals and instructional techniques, as well as content aspects that should be addressed in learning situations. The major challenge is that, while designing, the designer is unable to be certain about how well the artefact will perform. The performance of the artefact and the quality of the design are revealed only after the artefact is used in the context in which it is to operate. This leads to questions about the kind of knowledge that it is relevant to incorporate in the construction of the artefact. For instance, how much reliance may the designer place on learning models derived from theoretical foundations or empirical evidence? Hence, to evaluate the function and goals of the artefact, it is not sufficient to rely only on assessments related to pedagogical considerations. Assessments must also be conducted after the artefact has been used in a realistic context.

4 Methodology

The main issue that this thesis will cast some additional light on is: *How can the fire and rescue services be equipped with adequate principles, models and tools to achieve learning and enhance fire and rescue personnel's competence in tunnel fire safety?* The work behind this thesis aims to acquire new knowledge and a better understanding of how to improve learning processes within the fire and rescue services and subsequently develop fire and rescue personnel's competence in tunnel fire safety. To address this issue, the research focused on the following research questions (RQs):

- RQ1: How do the current educational framework and learning activities approach learning and competence, given that response operations in tunnels represent high-risk and challenging situations?
- RQ2: How do employees in the Norwegian fire and rescue services regard their own competence, and to what extent do their self-evaluations of competence reflect the actual level of competence within the Norwegian fire department?
- RQ3: What mechanisms are significant determinants to facilitate the process of learning within the fire and rescue services, and how is the outcome of learning affected by these mechanisms?
- RQ4: How can learning activities successfully be designed to enrich learning outcomes and enhance fire and rescue personnel's competence in tunnel fire safety?

The definition of the main research issue, with the subsequent research questions, was the driving force behind the research process and activities described in this chapter. In the following, I will describe how I approached learning and competence within the fire and rescue services from a methodological point of view, the research strategy for this study, and the approach regarding data collection and data analysis.

4.1 Analysing learning and competence within the fire and rescue services

Issues related to philosophy of science challenge researchers to reflect on the assumptions that underlie their work. For instance, "What does it take for fire and rescue personnel to learn and enhance competence in tunnel fire safety?" can be seen as the epistemological form of the question "How do we gain knowledge about the world?" Accordingly, questions concerning the status of knowledge, such as whether learning and competence is an objective truth or constructed and whether the concepts can be objectively observed, are essential. Guba and Lincoln (1994) argue that the methodological question *"How can the inquirer (would-be knower) go about finding out whatever he or she believes can be known?"* is determined by the answers given to the ontological and epistemological question (p. 108). The research approach adopted in this thesis acknowledges the *constructivism* paradigm to be a compelling lens through which learning and competence within the fire and rescue services may be understood. A common understanding within this paradigm is that of the beliefs of researchers as human constructions. Thus, all findings and answers are creations of the human mind and subject to human error. More specifically, *"no construction is or can be incontrovertibly right; advocates of any particular construction must rely on persuasiveness and utility rather than proof in arguing their position"* (Guba & Lincoln, 1994, p. 108). This thesis' purpose is not to compel the reader to accept the analyses and arguments on the basis of indisputable logic or evidence. Rather, the analyses and arguments hope to be credible and demonstrate their utility to facilitate learning processes within the fire and rescue services and subsequently enhance fire and rescue personnel's competence.

Research on workplace learning and competence is difficult from a methodological point of view because there is no common agreement on measurable outputs of the concepts. The researcher faces several challenges. The difficulty is due partly to the fact that, besides relating to individuals' cognitive reasoning, the concepts are also context-bound. Observing fire and rescue personnel's performance requires conducting real-time observations of tunnel fire events and activities while emergency response operations unfold. Since tunnel fires are rare events

and the personnel have limited experience of response operations in tunnels, the researcher lacks access to first-hand knowledge and must retrieve assumptions about competence from other sources. How to produce valid and useful knowledge is, however, a question partly of research perspective and partly of research strategy and design (i.e., sources and methods of data collection).

The research perspective, or theoretical framework, provides a way of analysing the world by setting the context and guiding the research actions (Blaikie, 2010; Fetterman, 2010; Yin, 2014). As emphasized by Blaikie, the role of theory is to *"highlight certain aspects while at the same time making other aspects less visible"* (Blaikie, 2010, p. 126). Analysing learning and competence within the fire and rescue services requires an examination of: (1) how learning and competence development is facilitated within the system in which the individual firefighter operates, (2) fire and rescue personnel's kinds and levels of competence, (3) the process of learning in emergency response work, and (4) the design of learning activities. Within this context, individual theories that combine cognitive constructivist and socio-cultural aspects of learning were regarded as suitable approaches (see Chapter 3.2). It is imperative that learning and competence within the fire and rescue services are regarded as more than an inner psychological process within the individual. It must also entail a consideration of the social interaction of the individual and the social environment in which learning and competence development occur (Braut & Njå, 2009; Illeris, 2010, 2011; Njå & Braut, 2010; Sommer et al., 2013).

Furthermore, a model for understanding learning in emergency response work has provided a powerful lens through which to examine learning processes within the fire and rescue services. The model for understanding learning in emergency response work focuses on the individual's need to learn, by emphasizing six interrelated aspects, i.e., *content*, *context*, commitment, *decision-making and response*, *reflection* and the *outcome of learning* (see Figure 5). The outcome of learning is understood as *changes* in structures, behaviours, cognition and processes, *confirmation* of existing knowledge and practices and *comprehension* of established tools, behaviours or working methods (see Chapter 3.3).

To acquire knowledge about how safety-related issues may be integrated into the contextual frame of learning and competence development within the fire and rescue services, Nancy Leveson's (2011) systems theory approach to safety was regarded as a well-suited approach. Systems theory suggests the imposition of constraints to regulate risk-related activities and ensure safety in complex systems (see Chapter 3.1). This approach served as a framework to identify how safety constraints may be integrated into existing learning processes and to assess the consistency between competence requirements for fire and rescue personnel and the current learning activities. Additionally, design science offered an empirical foundation that provided insight into how designers may think and act to develop learning activities and enhance fire and rescue personnel's performance in tunnel fire response operations (see Chapter 3.6).

Crandall et al. (2006) claim that, in order to observe performances in complex situations, it is not sufficient to only observe individuals' actions and behaviours. In such situations, it is also crucial to reveal how individuals think and what they know, as well as what information they seek to understand better. Assessing competence within the fire and rescue services requires analysis of fire and rescue personnel's strategies and priorities applied to the specific problems they encounter during emergency response operations in tunnels and descriptions of uncertainties and concerns for the situations in which they act. Thus, a theoretical framework that focuses explicitly on the specific set of attributes (i.e., knowledge and skills) that individuals bring to a job, the particular characteristics of the job and the situation in which competence occurs has been a suitable perspective for this thesis (see Chapter 3.4.1). Additionally, decision-making in complex work environments has been central to understanding competence within the fire and rescue services (see Chapter 3.5.1). In this context, competence is seen as having not an objective structure but, rather, a relative character. Hence, tunnel fire safety competence is not treated as a generic set of attributes amongst individuals but as a set of attributes subject to the taught practice of tunnel fire responses within a specific fire department. It was therefore necessary to acquire knowledge about the prevailing norms, standards and values of the fire department with regard to tunnel fire responses.

4.2 Research strategy

The research strategy should equip the researcher with a set of methods to answer the research questions (Blaikie, 2010). In this thesis, I used mixed methods research (MMR), with the use of participant observation, a comparative study and a pilot course in a fire department acknowledged as exemplary and well-informed about tunnel fire safety. Further, a national questionnaire was conducted to collect data from the Norwegian fire and rescue services. MMR *"combines elements of qualitative and quantitative research approaches (e.g., use of qualitative and quantitative viewpoints, data collection, analysis, inference techniques) for the broad purposes of breadth and depth of understanding and corroboration"* (Johnson et al., 2007, p. 123). Johnson and Onwuegbuzie (2004) argue that MMR draws from the strengths of both methods and counterbalances the weaknesses of one method with the strengths of another. A basic assumption is that the use of MMR strengthens the content validity or more precisely the extent to which a measurement reflects the subject matter that is being measured (Newman et al., 2013).

A principal aim of this thesis is to improve learning processes within the fire and rescue services, as well as provide insight into fire and rescue personnel's competence in tunnel fire safety. Both workplace learning and competence are context-dependent and considered to have an inter-disciplinary character. The literature suggests that, to study these phenomena, one must base the research on extensive empirical exploration, testing and application of practice across different types of research inquiry (Sawchuk, 2011). Analysing learning and competence within the fire and rescue services based on MMR was therefore well-suited in this study.

The study was designed so that the research altered between being exploratory, descriptive and normative through the different stages of the research process. Initially, an inductive approach, guided by data from a fire department, was taken as the research strategy for this work. The scope was to explore how the educational framework and learning activities address learning and competence, given that response operations in tunnels represent high-risk and challenging situations. The purpose was to acquire knowledge about the design and operation of the

tunnel fire safety learning system within the fire and rescue services. To understand the system and the contextual frame in which the individual firefighter acquires knowledge and skills, it was necessary to be present in the fire department and observe learning processes and activities. Participant observation is about observing people in their natural environment (Hammersley & Atkinson, 2007). My presence in the fire department was an important strategy that enabled me to develop an understanding of the fire department, its structure, governing documents, learning activities, procedures and action plans for responding to incidents in tunnels. This was essential because it helped me understand the contextual and cultural conditions within the fire department and equipped me with knowledge and skills to interpret the data and subsequently answer this thesis' research questions.

Further, it was necessary to investigate fire and rescue personnel's kinds and levels of knowledge and competence in tunnel fire safety. The decision to use a questionnaire was taken to capture the Norwegian fire and rescue personnel's self-evaluations of knowledge and competence regarding tunnels and responses to fires in their regions. At this point, the research strategy changed, and a deductive approach, guided by data from the national questionnaire, was taken to outline kinds and levels of knowledge and competence and facilitate a closer examination of the associations between the studied phenomena. Carrying out surveys can provide researchers with a wide range of 'people characteristics', the relationships between such characteristics and patterns of the results obtained (Robson & McCartan, 2016). The quantitative nature of the survey generated large amounts of data related to learning experiences, self-evaluations of knowledge and competence amongst the respondents, as well as detailed patterns of correlations and causal relationships between the phenomena studied.

The kinds and levels of knowledge and competence reported through the national questionnaire offered insight into respondents' self-evaluations and did not necessarily mean that it corresponded with their actual level of competence. An interesting lens through which to continue my study of competence within the fire and rescue services was therefore to analyse the extent to which respondents' self-evaluations of competence reflect the actual level of competence within the local fire department. *Actual competence* is understood as fire and rescue personnel's choices

of action when confronting fire events in tunnels and is reflected through the taught strategies and priorities of tunnel fire rescue work in which the informants were engaged. It was therefore interesting to seek patterns of response practices, using a comparative study in the local fire department, and thus return to the use of an inductive strategy. The key issue was directed towards informants' choices of action in two hypothetical tunnel fire scenarios and how their response practices deviate from the norms and practices established by the fire department for responding to tunnel fires.

Later on, as the thesis focused on understanding learning within the fire and rescue services, it was necessary to investigate which mechanisms are significant determinants to facilitate the process of learning, and how the outcome of learning is affected by these mechanisms. Evaluating the model for learning in emergency response work (see Figure 5) and investigating the significant learning mechanisms and their interactions has been fundamental to my research project. At this point, the research was guided by data from the national questionnaire, and statistical procedures were employed to evaluate the theoretical arguments behind the conceptualization of the learning model and the connections between its elements.

Insights into the current educational framework, fire and rescue personnel's kinds and levels of knowledge and competence, and the significant learning mechanisms and their interactions allowed the development of a pilot course for incident commanders in tunnel fire safety. The pilot course was an important part of the research process because it contributed to enhancing my understanding of how learning activities can be designed to enrich learning outcomes and enhance fire and rescue personnel's competence. Figure 6 illustrates the connections between the papers, research questions and the main research issue of this study.

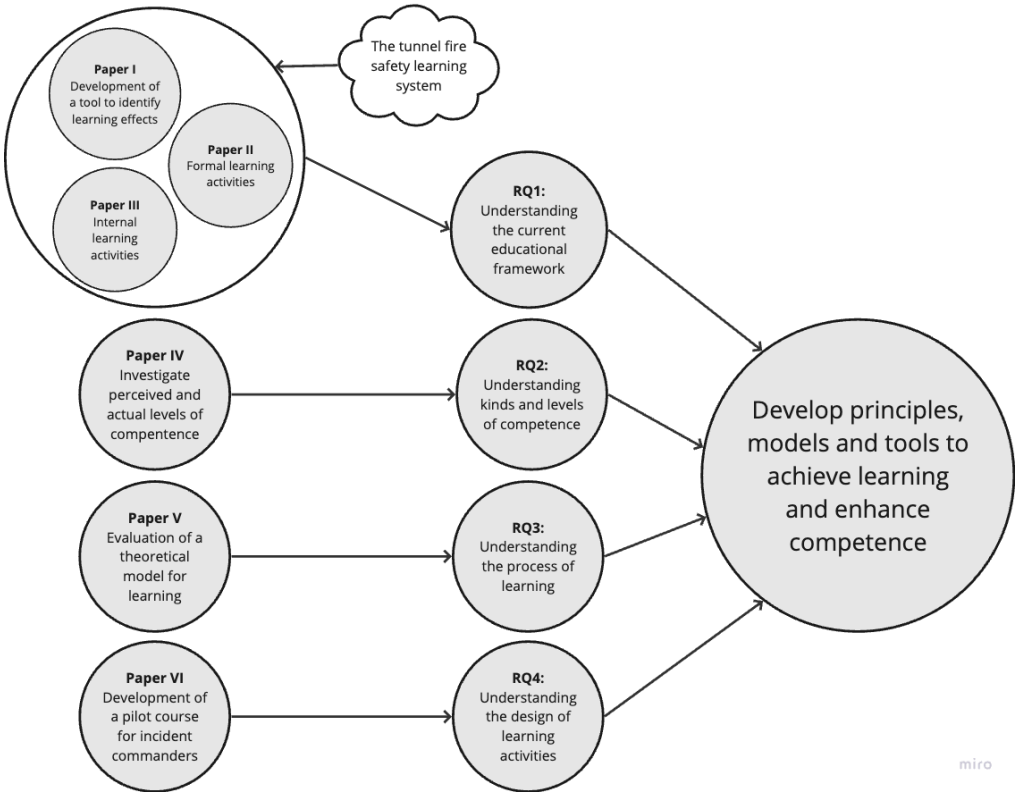

Figure 6: Illustration of the connections between the papers, the research questions and the main research issue

4.3 Research activities

In this research project, a series of research activities has been conducted. The principal aim of the research activities was to provide data that cover different parts of the main research issue. Table 1 provides an overview and description of the research activities conducted for this project. Further, Table 2 shows the connection between the research questions, the research activities and the papers included in Part II.

Table 1: Overview of research activities

#	Description of research activity	Unit(s) of study	Variables
A	Application of a theoretical framework for learning, to assess learning processes, with special attention paid to road tunnels. Important contexts are the process of learning in emergency response work and the handbook for cooperative exercises.	Learning processes	Principles, concepts, model parameters
B	Application of a systems theory approach to assess the Norwegian tunnel fire safety learning system. Important contexts are the regulatory framework behind the organization of the tunnel fire safety learning activities, formal learning activities and emergency response training arrangements.	Learning activities and competence requirements	Regulative framework, curricula, learning goals, learning content, methods, risk analysis
C	Tunnel fire safety knowledge and competence within the Norwegian fire and rescue services. Important contexts are fire and rescue personnel's perceived level of knowledge and competence in tunnel fire safety.	Kinds and levels of knowledge and competence	Tunnel's design, safety equipment, contingency plans, status from inspections, accessible resources, safety level, road users' behaviour, fire dynamics, own competence, fire department's competence
D	Fire and rescue personnel's capabilities to cope with major tunnel fires. Important contexts are fire and rescue personnel's actual levels of competence in tunnel fire safety.	Response practices	Strategies and priorities of tunnel fire rescue work, descriptions of uncertainties and concerns, deviations from taught practices
E	The process of learning within the fire and rescue services. Important contexts are the properties of the learning model and the	A learning model	Content, context, commitment, decision-making and response,

#	Description of research activity	Unit(s) of study	Variables
	interactions/relationships between the model's components.		reflection, the outcome of learning
F	Application of a design science approach to develop a pilot course for incident commanders. Important contexts are the design process and the methodological assumptions behind the development of the pilot course.	A pilot course	Scientific foundation, learning goals, learning outcomes, competence

Table 2: Connection between RQs and research activities A-F

RQ#	Research activities[1)]						Papers [2)]
	A	**B**	**C**	**D**	**E**	**F**	
1	M	M	-	-	S	-	I,II,III
2	-	-	M	M	-	-	IV
3	M	-	-	-	M	-	V, (I)
4	S	-	M	M	M	M	VI

[1)] M = Main contribution, S = Secondary contribution
[2)] A paper's secondary contribution is illustrated by parentheses

4.4 Sources of data

The different sources of data for this thesis are presented in Table 3. This table illustrates how the different sources of data connect with the research questions and research activities. For example, participant observation was relevant as data for two of the research questions and three of the research activities. Another example is that a pilot course for incident commanders was developed and carried out as input to answer research question 4 in research activity F.

Table 3: Sources of data and connection with RQs and research activities

Sources of data	***How can fire and rescue services be equipped with adequate principles, models and tools to achieve learning and enhance fire and rescue personnel's competence in tunnel fire safety?***				**Input to research activities:**
	RQ1	**RQ2**	**RQ3**	**RQ4**	
Participant observation	X			X	A, B, F
National questionnaire		X	X	X	C, D, E, F
Comparative study to identify actual competence		X		X	D, F
Pilot course: participant observations, evaluations, interviews				X	F
Papers	I,II,III	IV	V, (I)	VI	

4.5 Participant observation

The essence of participant observation is *"to learn about the activities of people under study in the natural setting through observing and participating in those activities"* (Kawulich, 2005, p. 1). The fire department where observations were carried out is one of the largest fire departments in Norway, covering 335,000 inhabitants in its 2600-km^2 area. It consists of 16 fire stations, of which four are 24-hour manned and located in the most densely populated areas of the region. Fire and rescue personnel employed in full-time and part-time positions number 450, working with emergency response and fire prevention tasks. Currently, the fire department has 27 tunnels in its field of responsibility. Amongst these, 22 are single-tube bi-directional tunnels without other emergency exits besides the tunnel portals. Further, four tunnels are long and complicated subsea tunnels with steep slopes (>5%). To enhance the emergency response personnel's knowledge and skills in tunnel fire safety, the fire department has developed an educational programme consisting of two theoretical lectures and three practical exercises. The

theoretical lectures address special characteristics and challenges related to tunnels and search and rescue tactics during tunnel fire responses. The practical part consists of two training exercises (i.e., vehicle fire in tunnel and search and rescue tactics) in an outdoor training facility, along with a tabletop exercise.

Looking back on my research into learning, I realize that I entered the field as a new beginner and experienced a process of learning, during which I gradually became familiarized with the structure and culture of the fire department. Observations of tunnel fire safety activities have provided insight into how the fire department approaches tunnel fire safety and facilitates learning and competence development. When reflecting on my own learning, it is interesting to note that my learning had arisen from my motivation to understand learning processes and facilitate competence development amongst fire and rescue personnel. Seeing myself as a learner was of great value and allowed me to make my own experiences with the theoretical underpinnings and the model of learning in emergency response work which have permeated this thesis' work (see Chapter 3).

During the four years of my stay in the fire department, I held a position as an independent PhD researcher and observed a wide range of tunnel fire safety learning activities. It is important to note that the fire department is anonymized through the research study, and my research does not represent an ethnographic study of the fire department. The observations conducted relate to formal and internal learning activities, the planning process and implementation of a new tunnel system's emergency response preparations, hazard identification (HAZID) meetings, inspections carried out jointly by the fire department and the road authorities, cooperation exercises between the emergency response services, and evaluation meetings in the aftermath of incidents. The benefit of observing these activities was that it helped me develop an understanding of the design and operation of the tunnel fire safety learning system in which learning and competence development occur.

Participant observation and data collection consisted of both observations of learning activities, where I was in the background, observing and taking notes, and participation in planning processes and other activities, where I was involved in discussions and wrote minutes

from meetings. Taking a more active role helped me establish close relationships with the employees at the fire department and was helpful in generating trust and open dialogue. This gave me access to first-hand knowledge and enabled me to acquire personal experience with the tunnel fire safety activities that the employees were involved in.

Notes were recorded during the observation and participation period and gathered in a separate folder. The data analysis process in relation to observations involved identifying patterns in the acquired material. Identifying patterns enabled the categorizing of sections of data representing a particular phenomenon. For instance, the categories referred to how tunnel fire safety learning activities were facilitated by the fire department and other involved parties (e.g., road authorities, police and health), the content of the learning activities, the instructional techniques, the employees' attitudes to learning and instructors' competencies.

To become familiar with the data and identify patterns that may provide answers to the research questions, the notes were read several times, reflections were noted in the margin and questions considered interesting to follow-up were raised. At times, informal discussions were necessary to better understand what was going on. These conversations were important and helped me understand less obvious sides of the fire department's approach to tunnel fire safety. For instance, after participating in meetings related to the Ryfast tunnel system's emergency response preparations, I noticed that there was slow progression in the emergency response system regarding the development of learning activities prior to opening the tunnel. Hence, to better understand the challenges that the fire department faces during these preparations, informal discussions were carried out with key personnel.

During the project period, I also had the opportunity to be involved in the SAFEINTUNNELS project, which is an Erasmus+ project for the vocational education and training of fire and rescue personnel in tunnel fire safety. This project became an essential part of the research and is discussed in more detail in Chapter 4.8. Since the overall objective of the project fitted very well with the major research issue of this study, I was offered a position in the fire department and became responsible for the

development of a course for incident commanders. The initial project period was therefore extended by one year, and I alternated between being an employee at the fire department and a researcher at the university.

A key aspect that should be emphasized is my affiliation to the fire department where the research activities were conducted. When becoming a member of the organization under research, the researcher may become distanced from the researcher role, and the analytical distance which is fundamental in scientific work and valid research may be difficult to obtain (Aase & Fossåskaret, 2007). Awareness of potential bias triggered by being 'too close' to the organization that I was studying was an important issue that I always kept in mind. At times, to gain distance from the study object, especially during the data analysis process, the research work was carried out at my office at the university. Furthermore, the data were collected periodically, with several months and up to a year between each period of data collection. From a methodological point of view, this enabled me to achieve some distance from the study object and reflect on the experiences and data acquired in the fire department, as well as keeping me close to the academic field.

4.6 A national questionnaire for fire and rescue services

Another main source of data used in this study was a national questionnaire for fire and rescue services. This research technique allows researchers to collect data about a given phenomenon in a highly structured way (Queirós et al., 2017). Moreover, the data collected can be quantified, and sophisticated statistical methods can be applied to assess the relationships between the variables measured. A comprehensive questionnaire was designed to capture respondents' kinds and levels of knowledge and competence in tunnel fire safety, as well as significant learning mechanisms within the fire and rescue services (see Appendix A). The questionnaire was developed, building on Braut and Njå's (2009) and Njå and Braut's (2010) theoretical framework of learning, the *Handbook for Exercise Planning* (Samvirkeaktørene, 2014), the textbook *Firefighting Operations in Road Tunnels* (Brauner et al., 2016) and discussions with tunnel experts in fire departments.

To ensure that the answers collected stem from a representative sample, the questionnaire was targeted towards employees involved in tunnel fire safety activities (i.e., fire prevention personnel, emergency response personnel and emergency central operators). The investigated aspects relate to, inter alia, the content of learning activities, efficacy of training exercises, motivational factors, experiences with incidents in tunnels, reflective activities and learning outcomes. The questionnaire also gathered information about respondents' education, employment position, formal training, experiences, nearby tunnels, etc. A major part of the questions was organized as assessments of experiences starting with "To what extent …", introducing a five-point Likert scale ranging from very small degree (score of 1) to very high degree (score of 5).

4.6.1 Pre-test and adjustment of the questionnaire

Common problems in developing valid indicators are question-wording and how people interpret the meaning of the questions (De Vaus, 1991). Before the content and design of the initial version of the questionnaire was established, different pre-tests of the items were performed and discussed between the authors and an expert panel composed of 16 representatives from the fire and rescue services, with both academic and non-academic backgrounds. The purpose of the pre-test was to increase the validity of the questionnaire by ensuring clear and concise questions, correct use of terminology, inclusion of all answer categories, and equal interpretations. It was also essential to determine the structure and systematization of the questions and the time required to answer. Confusions about terminologies and recognition of the meaning of questions asked were sought and the questionnaire corrected accordingly. However, a formal validation of the questionnaire items has not yet been performed, and the analysis included in this study was obtained with the preliminary questionnaire. Although minor adjustments were implemented, and some items were pointed out as challenging, no items were left out or conceptually changed before distribution of the questionnaire. The major suggested changes are listed in Table 4.

Table 4: Suggested adjustments of the questionnaire's items

Component	Suggestion	Description of change
Interpretation of the tunnel's safety equipment: low, medium, high	To avoid subjective assessments, there should be a written description related to the answer categories.	Explanation was added to each of the answer categories, e.g., "low - water supply and emergency stations", etc.
Interpretation of the content of the training and learning activities: coping with uncertainties	Uncertainty is a relatively abstract concept and may vary across individuals.	Explanation/examples were amended to the concept, e.g., uncertainty related to the fire medium, exposed people, time aspects, extinguishing strategies, etc.
Interpretation of the role related to incidents in tunnels	Respondents should have the possibility to give multiple answers. The personnel may have experienced different roles during emergency responses.	Additional text was provided to capture the most prominent role experienced during incidents in tunnels, e.g., "mark for the role you have had most of the times or the one you think was most important".
Interpretation of the description of critical tunnels	It appears to be challenging to describe five of the most critical tunnels in terms of the details requested without using aids. Such descriptions set high knowledge requirements for personnel.	No change provided; the knowledge dimension is arguably of direct relevance to personnel involved in tunnel fire safety work.
Interpretation of accessible resources "in your own fire department" and "in neighbouring fire department"	Some emergency centrals are subject to a single fire department, while others operate as inter-municipal companies having responsibility for several fire departments.	No change provided; we find the questions acceptable, as the intended purpose is to reveal both the local and regional perceived level of knowledge of accessible resources.
Interpretation of tunnel fire safety training and learning activities	It appears that personnel working with fire prevention tasks are not involved in tunnel fire safety training or learning activities.	No changes provided; the items seek to capture the extent and the content of the tunnel fire safety training and learning activities for all personnel involved in tunnel fire safety work.
Interpretation of perceived level of competence	The expression "called-out to action" is mostly relevant in the context of emergency response.	No changes provided; personnel involved in emergency response work were deemed the predominant group in the questionnaire.

Component	Suggestion	Description of change
Interpretation of the term "working tasks" in items related to training activities	The term may be experienced as diffuse and difficult to interpret.	Additional text was provided to the term, e.g., "…for my working tasks related to efforts/emergency response and/or other tasks concerning safety in tunnels".
Interpretations of the term "completed training" for items related to fire prevention work	The term is challenging, due to lack of systematic training requirements for personnel working with fire prevention tasks.	The term "completed training" was replaced with "involved in activities".
Interpretation of the term "discuss the content of the learning activities"	The formulation seems to imply the use of standardized methods.	A minor explanation was added, e.g., "before, during, or after a learning activity".

The section asking for a description of five critical tunnels in terms of safety was especially debated, as the feedback from several people indicated that such information extends beyond the traditional employee's knowledge requirements. Most of the group stated that even employees with particular interests in tunnel fire safety might barely possess such knowledge and therefore provide reasonable answers without using aids. The group argued that the large variety of tunnels makes it impossible to remember such detailed information. Hence, it was recommended to reduce the number of tunnels to be described, so that the respondents would not lose interest and drop out from the questionnaire. Considering that a major aim of the questionnaire was to gain insight into fire and rescue personnel's kinds and levels of knowledge and competence, we assumed that these questions would provide valuable information and decided not to reduce the amount of requested information.

4.6.2 Data collection

All fire and rescue chiefs with tunnels longer than one kilometre in their area of responsibility were approached by e-mail, and the data were collected by means of a web-based questionnaire. The e-mail contained a letter addressing the significance of the study, a link to the questionnaire and privacy information. We asked the fire and rescue chiefs to forward the questionnaire, with an encouragement to participate, to relevant employees involved in tunnel fire safety work and

reply to us with the following information: name of the fire department, total number of employees and number of employees who have received the questionnaire.

The first part of the data was collected between March and April 2019 and consisted of 200 responses. To enhance the response rate, we called all fire and rescue chiefs to provide more information about the study, motivate them to administer the questionnaire and send a reminder to participate. Through this anchoring with the fire and rescue chiefs, we sought to obtain a satisfactory response rate and thus strengthen the quality of the findings. In June 2019, the data consisted of 750 responses. However, we still lacked participation from four major fire departments responsible for many complex tunnels in their regions. Considering that those fire departments were located in counties with a high density of tunnels (Hordaland, Møre og Romsdal, Sogn og Fjordane and Nordland), we decided to visit them to ensure participation in the study. By the end of September 2019, we had succeeded in collecting an additional 189 responses. Participation was voluntary and anonymous.

4.6.3 The sample

In total, 1936 representatives from 113 fire departments were invited to participate in the study. These were the fire departments responsible for tunnels longer than one kilometre. In all, we achieved participation from 939 employees, respectively from 95 fire departments, yielding a response rate of 48.5%. Due to various reasons, some fire departments chose not to participate in the study. The arguments for not participating in the study were: (a) two fire departments had only one tunnel just under one kilometre, meaning that they did not represent the target group, (b) two fire departments were in the process of opening tunnels and, at this stage, could not provide any significant contributions, and (c) several fire departments did not have tunnels in their field but received the questionnaire because they were involved in some kind of cooperation with municipalities that did.

Amongst the 939 who answered the questionnaire, 290 answered only some of the questions, while 649 completed the questionnaire. However, the 290 respondents gave valuable information related to their vocational education and their role in the fire department. Hence, they were not

rejected from that part of the analysis. A majority of the 290 respondents that stopped their answering did so when they were asked to describe the tunnels at risk in their region. The reasons indicated for not completing the questionnaire were: 1) the respondents did not have sufficient knowledge to answer this section, and 2) the respondents did not have any experience of tunnel fire safety learning activities or training exercises.

The sample consists of 96% men and 4% women employed in full-time (61%) and part-time positions. The respondents' average age is in the 40-49-years category, with an average of 11-15 years of firefighting experience. All Norwegian counties (e.g., regional municipalities) are represented, with the highest number of respondents in the south-western part of the country. More precisely, these are Rogaland 20%, Hordaland 14%, Møre og Romsdal 13% and Sogn og Fjordane 9%. These are also the counties with the highest density of tunnels on the Norwegian road network. Most of the respondents belong to full-time fire departments (47%) and part-time fire departments with on-call duty (27%). Further, the majority belong to fire departments organized as inter-municipal enterprises (42%) and as enterprises in the municipality (41%).

To examine the representability of the sample, we contacted the DCP for additional information. More explicitly, we asked for the following data: the total number of employees for each of the fire departments that participated in the survey and their distribution by employment title and position. Table 5 illustrates an overview of the full sample population and its distribution by employment title and position.

Table 5: Overview of the full sample population and distribution by employment title and position

	Theoretical population		**Actual population**	
Employment title	**Full-time**	**Part-time**	**Full-time**	**Part-time**
Fire and rescue chief	60	26	57 (95%)	13 (50%)
Assistant chief of emergency response	36	16	27 (75%)	5 (31%)
Head of section of emergency response	22	0	15 (68%)	0
Chief of the fire brigade	20	0	13 (65%)	2
Emergency response leader	389	505	124 (32%)	120 (24%)
Firefighter	1207	2331	216 (18%)	221 (10%)

Assistant chief of fire prevention	23	0	23 (100%)	1
Head of section of fire prevention	13	0	5 (37%)	0
Fire prevention (without chimney sweep tasks) - fire inspector	271	16	39 (14%)	1 (6%)
Head of division of emergency central	13	0	1 (8%)	0
Emergency central team leader	40	0	15 (38%)	0
Emergency central operator	162	0	14 (9%)	0
Other	533	53	13 (2%)	1 (2%)
Total	2843	2947	562	364

A large group of the theoretical population (586 employees) belonged to other position categories. Those were not involved in tunnel fire safety work and considered to be irrelevant to the analyses of the material. In the actual population, 22 respondents belonged to other position categories. Among those, eight referred to the position "Shift leader of emergency response" and were included in the category "Emergency response leader". Moreover, 13 respondents did not answer the questions related to the employment title and position. Those are missing values in the analysis. It should also be noted that three of the personnel employed in part-time positions have non-existing categories in the theoretical population. A relevant explanation might be confusion related to the respondent's position or simply just wrong answers.

4.6.4 Statistical methods and techniques

The quantitative data used in Papers IV and V were first explored descriptively (mean, standard deviation, skewness and kurtosis) by the Statistical Package for the Social Sciences (SPSS) version 26. In Paper IV, we combine exploratory factor analysis (EFA) and analysis of variance (ANOVA). In Paper V, the statistical program M*plus* version 8.6 (Muthén & Muthén, 1998-2017) was used for confirmatory factor analysis (CFA) and structural equation modeling (SEM).

Factor analysis methods

Factor analysis represents a method that seeks to explore the underlying structure of a specific phenomenon (Field, 2018). The methods are used to identify the interrelationship among a set of observed variables and then, through data reduction, to group a smaller set of these variables into dimensions or factors with mutual characteristics (Pett et al., 2003). EFA was used to obtain an underlying understanding of the respondents' kinds and levels of tunnel fire safety knowledge. Eleven items measuring respondents' perceived level of knowledge were subject to principal component analysis (PCA) and direct oblimin rotation. Bartlett's Test of Sphericity and Kaiser-Meyer-Olkin (KMO) are statistical measures used to assess the adequacy of the sampling. Bartlett's Test of Sphericity determines whether the matrix correlations are significant ($p < 0.05$), while KMO indicates the proportion of variance amongst variables that might be common variance and should be greater than 0.5 as a bare minimum (Field, 2018). In Paper IV, Bartlett's Test of Sphericity (0.000) and KMO (0.86) indicate that the items are adequate for factor analysis. The analysis supported the isolation of three latent factors with eigenvalues exceeding 1, subsequently denoted as: I: *Emergency response and tunnel system knowledge*, II: *Practical tunnel condition knowledge*, and III: *Theoretical (physical and behavioural) knowledge*.

CFA is a theory-based approach used when researchers seek to assess the extent to which the hypothesized organization of a set of identified factors fits the data (Kim et al., 1978). This method plays an essential role in measurement model validation in path or structural analysis (Brown, 2015). The main objective for using CFA was to assess the degree to which Sommer et al.'s (2013) theoretical model of learning in emergency response work is consistent with the empirical data. The properties of the learning model were investigated, and the factorial structure of the measurement model was identified prior to conducting the SEM. The literature proposes a wide range of goodness-of-fit indices. Byrne (1998) stresses that assessments of model fit must be based on multiple criteria, taking into account theoretical, statistical, and practical considerations. A traditional measure often used to evaluate the overall fit of the model is the overall chi-square statistics. However, when CFA is used for construct validity evaluation, the following fit indices are recommended to estimate the model fit: Comparative Fit Index (CFI),

Tucker-Lewis Index (TLI), Root Mean Error of Approximation (RMSEA) and Standardized Root Mean Square Residual (SRMR) (Sun, 2005). Good model fit is indicated by a value of below .05 on the RMSEA and SRMR and above .95 on the CFI and TLI (Browne & Cudeck, 1992). In Paper V, the CFA fit statistics indicated that the suggested model fits the data. The fit measures were: Chi-Square = 240.429, CFI = 0.982, TLI = 0.978, RMSEA = 0.000 and SRMR = 0.000 for the predictor model, and Chi- Square = 0.000, CFI = 1.000, TLI = 1.000, RMSEA = 0.000 and SRMR = 0.000 for the predicted model. Hence, the analysis supported the construction of six dimensions entitled: I: *Content*, II: *Context*, III: *Commitment*; IV: *Decision-making and response*, V: *Reflection*, and VI: *Outcome of learning*.

Structural equation modelling

SEM is an umbrella term for analyses in which unobservable latent variables are estimated from observed indicator variables, and the estimation of relations amongst the latent variables are of key interest (Wang & Wang, 2019). An important concept in SEM is also the flexibility to model complex relationships amongst multiple concepts, including direct and indirect effects (mediation) and interaction effects (moderation) (Kline, 2016). SEM was used to evaluate Sommer et al.'s (2013) model of learning and examine which components of the model have a significant impact on the outcome of learning and how the outcome of learning is affected by the model's components. In the SEM modelling, the *outcome of learning* was regarded as a latent dependent variable, whereas *content*, *context*, *commitment*, *decision-making and response* and *reflection* were considered latent explanatory variables. We conceptualized a model, hypothesizing that *reflection* is predicted by *content, context, commitment, decision-making and response*. Further, the *outcome of learning* was hypothesized to be predicted by *content*, *context, decision-making and response* and *reflection*. The model was tested for indirect effects, by investigating whether *reflection* mediates the relationship between the *outcome of learning* and elements of *content*, *context*, *commitment* and *decision-making and response*. The significance of the indirect effects was tested through bootstrapping analysis (MacKinnon et al., 2007), requesting 1000 bootstrapped samples. In Paper V, the fit indices for the model yielded a good fit to

the data: Chi-Square = 320.857, CFI = 0.982, TLI = 0.978, RMSEA = 0.034 and SRMR = 0.032.

Analyses of variance

ANOVA deals with situations where there is one dependent variable and one or more independent variables to examine differences amongst means (Field, 2018). In Paper IV, we used ANOVA to examine differentiating patterns amongst fire and rescue personnel's kinds and levels of knowledge and competence in tunnel fire safety. We hypothesized that different groups amongst the respondents would differ in kinds and levels of knowledge and competence across two variables: *Employment position* and *The role related to emergency response operations*. These variables were treated as independent, while the knowledge and competence variables were treated as dependent. Consequently, we searched for statistical significance between the variables and the factors influencing fire and rescue personnel's kinds and levels of knowledge and competence. The analyses indicated significant differences ($p < 0.01$ and $p < 0.001$) in the respondents' self-evaluations of knowledge and competence. For the actual competence dimensions, the analyses revealed that *Employment position* was not statistically significant at $p < 0.05$. However, *The role related to emergency response operations* differentiated significantly for three of the competence dimensions: common situational awareness, facilitating self-rescue and confirming procedure.

4.7 Comparative study to identify actual competence

To capture measures of actual competence, a comparative qualitative study was conducted in which informants expressed response practices and priorities made in two distinct hypothetic tunnel fire cases in well-known tunnels (i.e., a 5.8-km subsea, single-tube tunnel and a 4.4-km subsea, single-tube tunnel located further away). This can be regarded as an unprepared examination situation, which coincides with actual and real tunnel fire incidents. The data consist of accounts provided by 30 informants, comprising 20 firefighters and 10 operational commanders. Amongst the informants, 26 were employed in full-time and four in part-time positions. The study was conducted in a fire department, acknowledged as being exemplary and well-informed about tunnel fire

safety. This fire department has approximately 30 tunnels in its area of responsibility and is perceived by other fire departments, including the authorities, to be highly competent. Additionally, for several years, tunnel fire safety competence development has been a main priority within the fire department. For instance, to gain new ideas and experiences about training and education, the international centre for tunnel fire rescue training in Switzerland was approached. Based on the Swiss training model, the fire department has developed its own tunnel fire safety educational programme which all employees must attend.

Asking participants to report their practices on hypothetical future events can provide useful data for the researcher (Crandall et al., 2006). However, it is essential that the accounts provided are tightly coupled to actual events. Two major tunnel fire scenarios were developed and employed to disclose levels of actual competence (i.e., strategies and priorities of tunnel fire rescue work and descriptions of uncertainties and concerns) (see Appendices B and C). Several courses of possible action were presented to the informants, and they were requested to select a subsequent order of priorities during three chronological phases in tunnel fire response operations: i) *alarm*/*en route* (in the vehicle), ii) *arrival* (outside the tunnel), and iii) *response* (inside the tunnel). The informants' priorities were reported on a scale from 1 (highest priority) to 5 (lowest priority). For each of the phases, the instrument contained seven statements. Hence, some statements were not given priority but acted as alternatives. The instrument included two open questions for which the informants were encouraged to describe their main concerns and address three activities they regarded as crucial to cope adequately with the described fire scenarios. The investigation proceeded with informants answering individually, with no access to aids or written materials.

A predefined priority list, comprising two fixed answer solutions based on the fire department's norms and practices for approaching tunnel fires, was used as a reference to assess informant's actual competence (see Table 6). The fixed answer solutions were embedded in the fire department's tunnel fire safety educational programme, which all informants had attended. The chosen strategies and priorities are the reference for assessing informants' deviations from the tunnel fire rescue norms and standards of the fire department. Actual competence is the expressed knowledge as assessed against the taught practices in the

informants' fire department. The actual competence was measured in deviations from the taught practices, the size of the deviations and their criticality. Crandall et al. (2006) claim that a limitation with such methods of inquiry is that the researcher will only learn about conditions that have been tagged as important and incorporated into the scenarios. Further, the researcher cannot be entirely sure that the reported order of choices of actions in the scenarios would also occur in real-life settings. Such scenarios do not fully capture the physical and mental stress that fire and rescue personnel are being exposed to in tunnel fire response operations and the feeling of mental exhaustion from balancing a range of difficult tasks, in which they will have to consider their own and road-users' safety.

Table 6: Summary of the predefined priority list used to analyse informants' deviations

Phase	**Scenario 1 – Van on fire – close by but uncertainties regarding explosion hazards**		**Scenario 2 – Truck on fire – distant tunnel**	
	Firefighters (priorities)	*Operational commanders (priorities)*	*Firefighters (priorities)*	*Operational commanders (priorities)*
Alarm en route	1. Seek information from leader (fire – what, where, road users in tunnel) 2. Seek information from leader – number of road users downstream of the fire 3. Confirmation from leader that ventilation is in predefined direction 4. Discuss/recognize with team potential hazards of the operation 5. Discuss/recognize with team possible response tactics	1. Seek information (fire – what, where, road users in tunnel) 2. Seek information – number of road-users downstream of the fire 3. Ensure that the team has a common understanding of the situation 4. Confirmation from RTC and 110 that ventilation is in predefined direction 5. Confirmation of all resources that are en route to the incident site	1. Seek information from leader (fire – what, where, road users in tunnel) 2. Discuss/recognize with team potential hazards of the operation 3. Seek information from leader – number of road users downstream of the fire 4. Discuss/recognize with team possible response tactics 5. Confirmation from leader of what steps the RTC has taken	1. Seek information (fire – what, where, road users in tunnel) 2. Seek information – number of road users downstream of the fire 3. Instruct RTC to broadcast radio instructions on Digital Audio Broadcasting (DAB) 4. Confirmation from RTC and 110 that ventilation is in predefined direction and clears the site 5. Confirmation of all resources that are en route to the incident site
Size up – outside tunnel	1. Ensure that no victims needing first aid are left outside tunnel 2. Ensure that the operation is understood	1. Ensure that no victims needing first aid are left outside tunnel 2. Request RTC and 110 to communicate Automatic	1. Ensure that no victims needing first aid are left outside tunnel 2. Expect clear goals with a tactical plan for the response from leader	1. Ensure that no victims needing first aid are left outside tunnel 2. Ensure that head-on traffic is evacuated and

	3. Ensure that head-on traffic is evacuated and vehicles parked and controlled 4. Seek updated information about the fire 5. Confirmation that RTC has launched radio instructions on DAB	Incident Detection (AID) and camera information 3. Request RTC to broadcast radio instructions on DAB 4. Establish contact with fire and rescue team on the north side 5. Ensure that head-on traffic is evacuated and vehicles parked and controlled	3. Ensure that head-on traffic is evacuated and vehicles parked and controlled 4. Update information about the fire 5. Ensure that additional resources are coming	vehicles parked and controlled 3. Ensure that the team has a common understanding of the situation 4. Communicate the goals and plan for the response tactics to first responders 5. Establish contact with fire and rescue team on the north side
Response at scene	1. Start first aid/CPR for victims in close vicinity 2. Ensure own safety 3. Start to mount hoses and secure area 4. Gather information about vehicles, people, etc. downstream 5. Initiate extinguishing	1. "Window report/9-8 message" on a common voice channel 2. Initiate first aid/CPR for victims in close vicinity 3. Critically assess all conditions that might threaten the safety of the first responders 4. Contact road users present for relevant information 5. Inform the crew/first responder teams	1. Start first aid/CPR for victims in close vicinity 2. Ensure own safety 3. Start to mount hoses and secure area 4. Initiate extinguishing 5. Gather information about vehicles, people, etc. downstream	1. Initiate first aid/CPR for victims in close vicinity 2. Critically assess all conditions that might threaten the safety of the first responders 3. Contact road-users present for relevant information 4. Gather information about vehicles, people, etc. downstream 5. Inform the crew/first responder teams

4.7.1 Contents of the scenarios

All of the instrument's alternatives were formulated as plausible choices of action, confronting the informants with multiple dilemmas and uncertainties. The two scenarios differed in complexity, with respect to both uncertainties involved and challenges encountered by fire and rescue personnel and cooperating resources. The first scenario contained visible flames from a large van and dense smoke development. The informants were informed that: the van belonged to a welding company, four lorries were parked 200 metres from the incident scene, the driver of the van tried to put out the fire but was unable to extinguish it, and during the tunnel closing operation several vehicles drove into the tunnel. The road traffic operators had initiated the tunnel's emergency response plan and the fire ventilation direction was activated in the predefined direction.

The second scenario contained fire and smoke development in a truck. The tunnel is quite distant from the predominant fire department, to which the response time is approximately 17 min. The informants were informed about the location of the fire and that: the truck driver had initiated necessary actions but was unable to extinguish the fire, road traffic operators had initiated the fire response procedures, i.e., closing the tunnel and initiating the fire ventilation in the predetermined direction. The smoke from the fire was directed 3-3.5 km towards the tunnel opening on the north side, and the flow of smoke (8 m/sec) exposed the downstream road users. The nature of the vehicle's goods was unknown, there was a traffic jam, a foreign bus had stopped 200 metres downstream from the incident site, and the road traffic operators had observed about 15-20 people walking towards the north. The major concern was people evacuating to the north in the tunnel, road users' reduced mobility and limited communication means (also foreign).

4.7.2 Analysing deviations from established norms and practices

The goal was not to assess whether the predefined priorities were appropriate or not. These are taught during training activities and reflect the fire department's norms and practices for tunnel fire responses. Rather, the goal was to assess the degree to which informants deviated

from the taught practices. The statements included in the instrument were formulated as evaluation criteria, denoting the following dimensions: *scenario uncertainty*, *information gathering*, *common situational awareness*, *lifesaving activities – patient treatment*, *facilitating self-rescue*, *firefighters' safety*, *clarifying response actions*, *confirming procedures*, *fire and rescue resources*, *response tactics* and *communication and cooperation*. Considering that firefighters and operational commanders have different tasks and responsibilities during response operations, response tactics were analysed as a dimension of firefighters' competence, while communication and cooperation were analysed as a dimension of the operational commander's competence. The dimension of scenario uncertainty was assessed based on the accounts given through the open questions.

The analysis consisted of a panel of four persons (i.e., two experts from the fire department and two of Paper IV's authors) evaluating the responses against predefined priorities. The panel counted deviations, assessed the sizes of the deviations and the criticalities for the emergency response performance. Two moderation meetings were held to discuss the collated responses, and informants' deviations for each of the evaluation criteria were established. Three categories of deviations were identified, and responses were categorized against them.

Slight and moderate deviations were those with less than three statements differing from the taught practices. *High deviation* is a definite deviation from the best practices and includes three or more statements deviating from the taught practices, albeit not judged as critical. *Severe deviation* represents critical failure in competence and was categorized as such if informants had more than three statements deviating significantly from the taught practices.

4.8 A pilot course for incident commanders

During the research period, I had the opportunity to be involved in the SAFEINTUNNELS project, which is an Erasmus+ programme on tunnel fire safety intended to enhance the status of vocational education and promote the recognition and transfer of fire and rescue personnel's vocational qualifications across the European states (Erasmus+ -

SAFEINTUNNELS – European Commission, 2022). The project was established as a collaboration between several organizations, respectively represented by two fire and rescue services, an educational institution and a consulting company. The major objective was to support the development of a tunnel fire safety educational framework that can be implemented throughout the European states and close the gap between the requirements for effective performance in tunnel fire response operations and fire and rescue personnel's development needs. To achieve this purpose, the European Commission has required the project partners to develop an integrated and standardized concept of training for fire and rescue personnel at different hierarchical levels. The work that I was engaged in concerned the development of a course for incident commanders. This project was considered especially interesting for this thesis, as it directly involved the development of tunnel fire safety learning activities. As a designer of the course, I had a strict focus on parameters enhancing learning based on Sommer et al.'s (2013) model of learning in emergency response work (see Chapter 3.3). In September 2021, a three-day pilot course was carried out in Stavanger, focusing on incident commanders' role and responsibilities in tunnel fire response operations.

In total, eleven incident commanders representing full-time and part-time fire departments, five instructors and two external evaluators participated in the pilot course. To obtain data that provide insight into the design of the course and participants' learning experiences, a range of evaluation activities were conducted. The evaluations were organized as participant observation, two plenary evaluation sessions, questionnaire responses and semi-structured interviews.

Prior to the initiation of the learning activities, a questionnaire was administered to capture participants' assessments of tunnel fire safety knowledge. The learning goals were specifically addressed in this questionnaire and formulated as measurement scales comprising assessments of learning experiences introducing a five-point Likert scale ranging from 1 (very small degree) to 5 (very high degree). Aiming to examine learning effects from the pilot course, the same questionnaire was administered after the completion of the learning activities, and

participants were requested to report once more their assessments of tunnel fire safety knowledge (see Appendix D).

4.8.1 Interviews

To capture participants' learning experiences and investigate the design of the course, the eleven incident commanders that attended the pilot course were interviewed. In the interviews, a semi-structured method was applied, using a pre-made interview guide (see Appendix E). The interview guide was developed based on the six elements of Sommer et al.'s (2013) model of learning: i.e., *content*, *context*, *commitment*, *decision-making and response* and *the outcome of learning*. The semi-structured method was chosen because it allows flexibility to explore spontaneous issues raised by the interviewee (Ryan et al., 2009). In all my interviews, I did, to some degree, go beyond the interview guide to clarify the information that emerged. These interviews with the participants complemented the data that were collected during field observations, the plenary evaluations and the questionnaires because the interviews allowed for conversations about participants' learning experiences and the design of the course. The interviews lasted for approximately one hour and took place at the fire department. All the interview sessions were recorded and then transcribed verbatim.

4.9 Ethical issues

The ethical considerations posed by the kind of research conducted in this study relate to confidentiality, clarification of expectations regarding the research project and establishment of a 'contract' between the research and the participants. The Norwegian Centre of Research Data (NCRD) approved the formal application of the research activities conducted in this thesis (see Appendix F). The ethical responsibility for the participants was taken into consideration prior to, during and after the intervention, as well as during the data collection. All respondents to the national questionnaire were given relevant information about the purpose and relevance of the research project, as well as how results are going to be used. Further, all participants in the qualitative study and the pilot course were informed about the research project, and their right to consent or withdraw from the study at any point was clearly stated.

Participation was voluntary and their decision to participate was based on written informed consent.

5 Major findings

The overall goal of this research was to acquire knowledge about how to facilitate learning processes within the fire and rescue services and enhance fire and rescue personnel's competence in tunnel fire safety. From this research aim, four research questions were formulated and addressed in six research papers. Table 7 shows the research questions and the associated papers.

Table 7: Research questions and associated papers

No.	Research question	Paper no.
1	How do the current educational framework and learning activities approach learning and competence, given that response operations in tunnels represent high-risk and challenging situations?	I, II, III
2	How do employees in the Norwegian fire and rescue services regard their own competence, and to what extent do their self-evaluations of competence reflect the actual level of competence within the Norwegian fire department?	IV
3	What mechanisms are significant determinants to facilitate the process of learning within the fire and rescue services, and how is the outcome of learning affected by these mechanisms?	V
4	How can learning activities successfully be designed to enrich learning outcomes and enhance fire and rescue personnel's competence in tunnel fire safety?	VI

Aiming to gain insight into the frame conditions behind the tunnel fire safety educational framework and the fire and rescue services' approach to learning and competence development (research question 1), the research started by exploring learning processes in emergency response work, with special attention paid to tunnel fire safety. From this work, a tool for identifying and following-up learning effects from initiated learning activities and cooperation exercises was developed. Findings from this initial research showed that the frame conditions for developing optimal learning systems within the fire and rescue services are not in place, and that risk assessments framing competence requirements for emergency personnel are scarce in the current learning activities. Hence, an interesting aspect was to investigate fire and rescue personnel's kinds

and levels of competence in tunnel fire safety (research question 2). A main finding from this work was that there are inconsistencies between fire and rescue personnel's self-evaluations of competence and their actual level of competence, and that the tunnel fire safety response practices differed widely.

Another important aim of this thesis was to present a rich and detailed account of learning processes within the fire and rescue services (research question 3) and how learning activities can be designed to enrich learning outcomes and enhance fire and rescue personnel's competence (research question 4). In the following subchapters the major findings of each paper are presented.

5.1 Summary of Paper I

Bjørnsen, G., Njå, O. & Braut, G.S. (2020). A tool to assess learning processes based on the cooperation principle. This paper was first presented in 2018 at the World Congress on Engineering Asset Management Conference and won a prize for the best paper in the category of Asset Risk and Safety. The paper was further developed as a book chapter in J.P. Liyanage, J. Amadi-Echendu & J. Mathew, (Eds.) *Engineering assets and public infrastructures in the age of digitalisation*, pp. 87-95. Springer.

Emergency response organizations consider cooperation exercises important activities for learning and improving performance during emergency response situations. The model for learning in emergency response work (Sommer et al., 2013) is used to examine the relationships between the guidelines of the *Handbook for Exercise Planning* (Samvirkeaktørene, 2014) and how learning is achieved. The empirical foundation of this paper is based on a combination of learning theories (i.e., the cognitive constructivist approach – learning as acquisition – and the socio-cultural approach – learning as participation) and data derived from the fire and rescue service's involvement in cooperation exercises. The paper introduces an evaluation tool and a method for identifying and following up learning effects from cooperation exercises and real event operations, focusing on tunnel fire safety. The evaluation tool suggests that learning outcomes must be expressed as *changes* in structure, behaviour, working methods and processes, *confirmation* of existing

knowledge and work practices and/or *comprehension* of activities, practices and behaviour. Further, assessments of whether and how learning takes place require a systematic identification of learning outcomes within the different hierarchical levels in the emergency response system. It is suggested that expressions of change, confirmation and/or comprehension must be identified from the individual level to the organizational and interorganizational levels and up to the national and international levels where regulations and general standards are created.

The handbook specifies two areas for evaluation (Samvirkeaktørene, 2014). The first part focuses on the planning, management and execution of the actual process, so that the exercises committee can improve the planning and structure of future exercises. The second part concentrates on the evaluation of the performance of the participants and the emergency response system during exercises. The underlying concepts of these evaluations may be empirically observed as expressed phenomena in performance during emergency responses or exercises and must be related to the interactions between the different agencies. Even though each agency is responsible for their own activities and performance, the quality of the cooperation must be monitored at the intersections. Good and efficient cooperation must be visible at the individual level and not merely described in a normative way at procedural and standards' levels. Our method includes all the steps in this learning process, with important parameters in each step.

5.2 Summary of Paper II

Bjørnsen, G., & Njå, O. (2019). Applying systems theory to increase competence in tunnel fire safety – Focusing on the fire and rescue services. In: *Proceedings of the 29th European Safety and Reliability Conference (ESREL).* Hannover, Germany. Research Publishing Services.

This paper studies the tunnel fire safety educational framework within the fire and rescue services and discusses how the Norwegian tunnel fire safety learning system can be modelled to increase fire and rescue personnel's competence by combining a systems theory approach (Leveson, 2011) and a model for learning in emergency response work

(Sommer et al., 2013). The data collection in this paper is derived from examining the frame conditions behind the development and implementation of the tunnel fire safety learning activities.

The regulation regime addresses some requirements for learning and competence in tunnel fire safety for fire and rescue personnel. However, these requirements are seldom made explicit. Competence is understood as fire and rescue personnel's capability to apply accumulated knowledge and skills in everyday and unpredictable situations (NOU, 2012:8). The expected learning outcomes are expressed through hierarchical categories of cognition (i.e., know, understand, master), spanning from learners' ability to remember knowledge and information to the ability to understand and use knowledge and information to think critically and solve problems (NFRA, 2019). To ensure sufficient competence and adequate performance during emergency situations in tunnels, the curriculum for the basic training for firefighters includes a topic of two hours, dedicated to *"various challenges related to incidents in tunnels"* (p. 14). The learning outcomes are expected to be reflected through learners' ability *"to remember and recognize examples, actual conditions, methods and general conditions"* (p. 7). The analysis suggests that the conditions for developing efficient learning systems are not yet in place, and that the current approach leads to narrow understanding of tunnel fire safety learning practices. Furthermore, monitoring tools and feedback mechanisms providing information on the efficacy of learning activities are almost absent, and evaluations of learning practices are rarely addressed.

This paper concludes that, overall, the responsibility for developing and implementing tunnel fire safety learning activities is to a large degree left to the local fire department. In such an enforced self-regulation regime, educators and practitioners are free to choose amongst a variety of learning goals, contents and methods to approach learning and enhance fire and rescue personnel's competence. The fire departments have various and often limited pedagogic backgrounds for preparing effective learning activities. Thus, it is questionable whether fire and rescue personnel are sufficiently equipped to deal with major tunnel fire safety challenges and complex emergency responses. A set of safety constraints

expressing the performance of learning is recommended to facilitate observation and evaluation of parts of the learning process.

5.3 Summary of Paper III

Bjørnsen, G., & Njå, O. (2020). Competence constraints for fire and rescue personnel involved in tunnel fire safety as part of the tunnels risk acceptability. In: *Proceedings of the 30th European Safety and Reliability Conference and 15th Probabilistic Safety Assessment and Management Conference (ESREL2020 PSAM15)*. Research Publishing Services.

The aim of this paper was to investigate connections between competence constraints amongst fire and rescue personnel and the tunnels' risk acceptance criterion. Currently, the Norwegian Public Roads Administration (NPRA) has not established general risk acceptance criteria for tunnels. To reveal relationships between levels of risk acceptance and requirements for effective performance during emergency situations in tunnels, results from the Ryfast tunnel system's risk analysis and the emergency response service's preparations prior to the opening of the tunnel were examined. Leveson's (2011) systems engineering approach for complex socio-technical systems served as a guideline for the analysis of tunnel fire safety management.

A main assumption is that the emergency response services' capability to cope with major incidents and their related levels of competence contribute to specific risk levels in tunnels. The analysis indicates that these relations are not outlined in safety documents as criteria to assess the tunnels' accepted level of risk. Risk analyses are important tools to provide decision support for the preparations of the emergency response services. However, the existing risk analysis for the Ryfast tunnel system does not contain detailed information about the scenarios that are assessed, the performance of safety barriers or the characteristics of the fires and their severity. Further, assessments that address the performance of the emergency response services are not included. To enhance tunnel fire safety, it is necessary to replace the current approach to risk analysis with a more comprehensive one that takes both technical and social aspects of the tunnel system into account.

In the Ryfast case, learning and competence development was addressed through introductory visits, information booklets and practical exercises. The two scenarios that were developed for the practical exercises differed in the sense that one focused on extinguishing tactics, while the other focused on search and rescue tactics. Both exercises were designed with learning outcomes reflecting different levels of performance requirements for fire and rescue personnel. However, uncertainties and limitations associated with the tunnel's specific characteristics and how these may affect the response operation were not included. Rather, the focus was on basic skills training in terms of how to utilize the tunnel's available resources. Thus, experiences providing insights into aspects and situations that may challenge the fire and rescue service's emergency response capability were not acquired.

Overall, this paper suggests that development and enforcement of competence constraints for fire and rescue personnel involved in tunnel fire safety work is needed. Developing and enforcing competence constraints for personnel that are supposed to interact during emergency situations in tunnels requires that the performance of emergency response services is expressed in the tunnels' risk analysis. In the process of enhancing safety management in tunnels, a close relationship between risk analysis, derivation of competence constraints and development of learning activities is necessary.

5.4 Summary of Paper IV

Bjørnsen, G., Billett, S., & Njå, O. (2023). First responders' perceived and actual competence in tunnel fire safety. *Fire Safety Journal*, 136, 103758.

A fire department's responses to specific tunnel fires are event-dependent and subject to first responders' assessments and choices of action. Understanding kinds and levels of knowledge and competence within the fire and rescue services is important to inform learning activities and practices and thereby to improve safety in tunnels. As previously mentioned, former research has found practices regarding tunnel fire safety to be unclear and fragmented and the competence of first responders to differ widely (Njå & Svela, 2018). This paper examines first responders' self-evaluation of competence (i.e.,

perceived) against their taught competence (i.e., actual) in tunnel fire safety. The analysis is based on results from a national questionnaire and a detailed study conducted in a local fire department.

The national questionnaire indicates that the respondents characterize their tunnel safety knowledge in three distinct dimensions: i) *Emergency response and tunnel system knowledge*, ii) *Practical tunnel condition knowledge* and iii) *Theoretical (physical and behavioural) knowledge*. The respondents generally scored highly on items related to assessments of *Emergency response and tunnel system knowledge* and of *Theoretical (physical and behavioural) knowledge*. At the same time, the respondents achieved low scores on items related to assessments of *Practical tunnel condition knowledge*. The respondents were also asked to assess their competence and the fire department's competence to cope with major tunnel fires. The results suggested that the respondents had higher opinions of the fire department's competence than of their own competence.

A one-way between-groups ANOVA was conducted to explore differences in respondents' self-evaluations of knowledge and competence across two variables: *Employment position* (i.e., full-time and part-time) and *The role related to emergency response operations* (i.e., firefighters and leaders). The results showed statistically significant differences at the $p < 0.01$ and $p < 0.001$ levels on all self-evaluations of knowledge and competence. In all, the results of the analyses illustrated that personnel employed in full-time positions and leaders assessed their knowledge and competence as higher than did personnel employed in part-time positions and firefighters.

Next, results from the detailed study suggest that first responders tend to approach a high deviation of competence for dimensions related to scenario uncertainty, lifesaving activities – patient treatment, facilitating self-rescue and confirming procedures. Also here, a one-way between-groups ANOVA was conducted to investigate differences in first responders' actual competence across *Employment position* and *The role related to emergency response operations*. The results showed no statistically significant differences at the $p < 0.05$ level for the different competence dimensions in the mean scores across first responders' employment position. However, the role in emergency response

operations showed statistically significant differences at the $p < 0.05$, $p < 0.01$ and $p < 0.001$ levels on common situational awareness $F(1, 28) = 6.48$, $p = 0.0017$, facilitating self-rescue $F(1, 28) = 6.64$, $p = 0.015$ and confirming procedures $F(1, 28) = 8.37$, $p = 0.008$. More precisely, firefighters were found to have less deviation on common situational awareness ($M = 2.20$ and $M = 2.90$) and higher deviation on facilitating self-rescue ($M = 3.75$ and $M = 2.80$) and confirming procedures ($M = 3.70$ and $M = 2.70$), compared to operational commanders. In all, these results indicate that leaders might possess a higher level of actual competence for dimensions related to facilitating self-rescue and confirming procedures.

The qualitative analysis investigates the contents of the deviations from a holistic perspective and shows varying priorities and choices of action amongst the informants. For instance, most of the informants expressed concerns regarding the risks and uncertainties that may affect the extinguishing operation and their personal safety, whereas very few raised concerns abouts the performance of the engineered systems (e.g., communication systems, ventilation systems, passive fire protection and evacuation systems) and the conditions affecting road users' health and safety. There were also varying attitudes amongst the informants towards engaging in comprehensive assessments of risk prior to initiating the response operation and choosing strategies and actions that extended beyond the established procedures. Furthermore, patient treatment was considered to be other emergency services' responsibility, and the role of the RTC was limited to assisting information gathering and initiating the tunnel's fire response procedure (i.e., closing the tunnel and initiating fire ventilation). For example, when arriving at the incident scene, many choose to engage in actions related to gathering additional information to initiate the extinguishing operation, rather than providing medical assistance to people in close vicinity or ensuring that the RTC provides support to assist road users' evacuation.

This paper concludes that there is a gap between first responders' perceived and actual competence. Contrary to the national questionnaire, the qualitative analysis did not identify assessments and judgements that differentiated leaders from firefighters.

5.5 Summary of Paper V

Bjørnsen, G., Dettweiler, U., Njå, O., & Knudsen, K. (2022). Towards an understanding of learning within the Norwegian fire and rescue services – Focusing on tunnel fire safety. *Journal of Workplace Learning* 35 (1), pp. 112-128.

Understanding learning within the fire and rescue services is important for deciding how to best structure and design educational programmes and learning activities. The more the process of learning is understood, the more focused will be efforts to develop fire and rescue personnel's competence and enhance performance during emergency situations. The aim of this paper was to investigate how learning within the fire and rescue services may be conceptualized, with special attention paid to tunnel fire safety. The context for this study was to assess Sommer et al.'s (2013) model of learning in emergency response work, based on data acquired from a national questionnaire. Multivariate methods were applied to identify the measurement model and examine the structural relations between the factors.

The factorial structure of the measurement model was tested using CFA. The analyses showed a model structured of five plus one dimensions assumed to influence the process of learning. The dimensions were entitled: (i) *Content*, (ii) *Context*, (iii) *Commitment*, (iv) *Decision-making and response*, (v) *Reflection*, and (vi) *Outcome of learning*. The model showed good fit indices: $\chi^2 = 240.429$, CFI = 0.982, TLI = 0.978, RMSEA = 0.035 and SRMR = 0.033 for the predictor model, and $\chi^2 = 0.000$, CFI = 1.000, TLI = 1.000, RMSEA = 0.000 and SRMR = 0.000 for the predicted model. To investigate the structural relations between the factors, we proposed and tested an SEM in which *reflection* was predicted by elements of *content*, *context*, *commitment* and *decision-making and response*. Further, the model was tested for indirect effects, by investigating whether *reflection* mediates the relationship between the *outcome of learning* and elements of *content*, *context*, *commitment* and *decision-making and response*. This model also showed good fit indices: $\chi^2 = 320.857$, CFI = 0.982, TLI = 0.978, RMSEA = 0.034 and SRMR = 0.032.

The SEM model revealed that *reflection* is positively associated with the *content* of what is being learned ($\beta = 0.433$, $p < 0.001$) and with learners' *commitment* to learning activities ($\beta = 0.368$, $p < 0.001$). Furthermore, the *outcome of learning* is negatively associated with *decision-making and response* ($\beta = -0.072$, $p < 0.05$) and positively associated with the *content* of what is being learned ($\beta = 0.187$, $p < 0.001$), the *context* of learning ($\beta = 0.074$, $p < 0.05$), learners' *commitment* to learning activities ($\beta = 0.272$, $p < 0.001$) and *reflection* ($\beta = 0.431$, $p < 0.001$). The analyses also found that the effect of the *content* of what is being learned ($\beta = 0.187$, $p < 0.001$) and of learners' *commitment* to learning activities ($\beta = 0.159$, $p < 0.001$) on the *outcome of learning* is partially indirect and mediated through *reflection*. These findings corresponded well with the theoretical framework (Braut & Njå, 2009; Njå & Braut, 2010; Sommer et al., 2013) of learning in emergency response work. However, contrary to this, an unexpected finding was that the mediating effect of *reflection*, through the *context* of learning and *decision-making and response*, on the *outcome of learning* was not statistically significant.

Overall, the findings from this study confirmed the theoretical model and suggest that the content of what is being learned, the context of learning, learners' commitment to learning activities, involvement in decision-making and responses and reflection influence the outcome of the learning process. In addition, the results revealed reflection to be a powerful mechanism behind learning.

5.6 Summary of Paper VI

Bjørnsen, G., & Njå, O. (2023). Vocational learning of incident commanders in tunnel fire safety. *Vocations and Learning: Studies in Vocational and Professional Education*.

The designing, implementing and evaluating of educational programmes and learning activities demand thorough deliberations of *what*, *why* and *how* learning takes place. This paper combines principles of design science (March & Smith, 1995; Simon, 1996) and a model for learning in emergency response work (Sommer et al., 2013) to develop a course for incident commanders involved in tunnel fire safety work. The empirical data for this paper were acquired from a pilot course and

consist of participant observation, plenary evaluations, questionnaire responses and semi-structured interviews. Drawing on this, this paper discusses the design of the course and the factors that are most likely to promote and inhibit learning.

The results show that, to enable learning and enhance incident commanders' competence, the learning activities must be tailored to the learners' particular learning needs (i.e., learning goals, contents, instructional techniques). Sommer et al.'s (2013) model for learning in emergency response work, together with practical experience from the local fire department where the pilot course was carried out, has provided structured guidance and experiences to address specific aspects of learning within the fire and rescue services and the knowledge and skills (i.e., competence) required for effective performance during tunnel fire responses.

The evaluations revealed that the progressive introduction to new reinforcements through theoretical lectures and practical exercises (i.e., physical role-play exercises and tabletop exercises) was highly appreciated and helped the participants to create and understand new knowledge and experiences. The physical role-play exercises were also considered meaningful and enabled the participants to directly link their prior knowledge and experiences to challenges and dilemmas encountered in real-world settings. Further, the transition from physical role-play exercises to tabletop exercises allowed accumulated knowledge and experiences to be incorporated into higher levels of abstraction, by critically reflecting on the current response tactics and strategies. Overall, it was expressed that the sequences of learning activities, along with the local knowledge emphasis and the guidance from more experienced others and experts (i.e., colleagues and instructors), stimulated participants to engage in incrementally more complex tasks and develop their problem-solving abilities and decision-making skills. However, to achieve this, it is essential that trust and an open atmosphere, where creativity is encouraged, is facilitated during the learning situations.

According to the questionnaires and the interviews, the pilot course was a useful tool for facilitating learning and enhancing incident commanders' competence in tunnel fire safety. Generally, participants

expressed that, after attending the pilot course, they felt more confident in their roles and better prepared to deal with potential incidents in tunnels. During the evaluations, limitations associated with learning were also identified. Some of the limitations were related to lack of representativity from the tunnel emergency response system (i.e., health, police, road traffic and emergency operator) and insufficient methods to ensure critical reflective thinking within the participating group. In essence, the pilot course has the potential for further development but can be regarded as a promising effort in the process of developing incident commanders' competence.

6 Discussion of findings, contributions and assessment of research quality

This study has provided insight into several issues related to learning and competence in tunnel fire safety within the fire and rescue services. In this chapter, four important topics are addressed: 1) differences between first responders' perceived and actual competence and how competence development is approached, 2) a combined approach to understand learning and the usefulness of the model for learning in emergency response work, 3) the contributions of the research and 4) assessment of the research quality.

6.1 Tunnel fire safety competence within the Norwegian fire and rescue services

The performance of the fire and rescue services is an important part of the tunnel fire safety management system. Fire departments' responses to specific tunnel fires are event-dependent and subject to personnel's assessments and choices of action. The literature emphasizes situation assessment as the process that leads to situation awareness (Endsley, 2006; Flin et al., 2008). The main issue is how well the personnel interpret the information from the environment to create situation awareness and how appropriate the decisions and response actions are during emergency response situations in tunnels. The literature on workplace learning and competence development addresses competence as individuals' ability to meet appropriately complex demands in a particular context which usually is unforeseen (Illeris, 2010). Thus, competence is subject to individuals' skills and knowledge but also to their attitudes and values (Jørgensen, 1999). Competence within the fire and rescue services was analysed in relation to the specific set of attributes (i.e., knowledge and skills) applied by the personnel when choosing strategies and tactics during emergency situations in tunnels and the specific context in which their decisions and response actions occurred. Drawing upon the behaviourist/cognitivist and constructivist perspectives on competence, personnel's interpretations and experiences of the contextual features when responding to tunnel fire scenarios were

decisive for understanding tunnel fire safety competence within the fire and rescue services (e.g., Dall'Alba & Sandberg, 1996; Ellström, 1997; Pate et al., 2003; Sandberg, 2000; Schön, 1991).

6.1.1 Perceived versus actual competence

My study of tunnel fire safety competence within the Norwegian fire and rescue services analysed first responders' self-evaluation of knowledge and competence (i.e., perceived) as reported in the national survey against their taught competence (i.e., actual) in a local fire department. The study found significant differences between first responders' perceived and actual competence (Bjørnsen et al., 2023).

We may think of tunnel fire safety knowledge as comprising *emergency response and tunnel system knowledge* (i.e., knowledge of the tunnel's design, emergency response plans, procedures and resources), *practical tunnel condition knowledge* (i.e., knowledge related to the maintenance and functionality of the tunnel's safety systems) and *theoretical knowledge* (i.e., knowledge of fire dynamics and evacuation behaviour). With the exception of the practical tunnel condition knowledge, which was regarded as low, the respondents' self-evaluations of knowledge and competence were relatively high. Further, the respondents' self-evaluated knowledge and competence differed across employment position and whether or not the fire department operated as a part-time or full-time service. In general, the results indicated that the respondents were confident in the fire department's capability to tackle major tunnel fires. Looking into investigations from previous tunnel fires which have debated the fire and rescue services' response work (NSIA, 2013; Njå & Kuran, 2015), it is relevant to ask what kind of incidents the respondents might consider challenging to the fire department's response capability and when their limitations to cope with such incidents will occur.

Considering the fact that tunnels represent high-risk and challenging environments for fire and rescue personnel and road users, it was surprising that their specific knowledge of safety levels in tunnels and how safety systems are maintained and function was scarce. Knowledge related to the maintenance and functionality of the tunnel's safety systems and how such aspects may affect tunnel fire safety and emergency response operations is not addressed in the current learning

activities. This is perhaps a result of how relevant actors within the fire and rescue services understand and approach the issue of tunnel fire safety. Looking at the educational framework and the content of the tunnel fire safety learning activities, the emphasis is on disseminating general knowledge related to emergency response challenges during incidents in tunnels. From a more holistic point of view, the ideal might be that the content of learning activities also provides specific knowledge of safety levels in tunnels and the connections between the condition of safety systems and emergency response situations. Knowledge and understanding of accepted safety levels and safety systems in local tunnels might generate discussions about how tunnel fire safety should be understood and approached by the fire department in different kinds of emergency response situations. Consequently, this knowledge may be integrated into procedures and response practices (i.e., fire ventilation strategy) to improve performance in tunnel fire responses.

The local study revealed another picture characterized by inconsistencies between the taught practices and those enacted by the personnel when responding to actual fire events in tunnels. The qualitative analysis did not reveal any clear differences in levels of competence between the informants' employment positions. Actual competence was understood as the ability to prioritize, in accordance with taught practice of tunnel fire response, and was measured in deviations from the taught practice. Even though all informants have attended the fire department's tunnel fire safety training programme, the analysis showed that their expressed choices of action deviated from the predefined priority list as taught by the fire department. However, despite the identified deviations, for many of the informants, it was possible to deduce a rationality in the way they answered and prioritized their response actions. For instance, some informants prioritized initiating search and rescue and extinguishing the fire prior to gathering critical information (i.e., number of vehicles and people downstream in the tunnel) to assess the situation. Others prioritized receiving confirmation that all resources are en route to the incident site rather than instructing RTC to broadcast radio instructions and guide the evacuation process. The point here is that, during emergency response situations, these informants usually receive instructions from leaders, and decision-making is outside their roles.

The hierarchical structure of the fire department's emergency response management expects the incident commander to gather information relevant to the incident, assess the situation and then make appropriate operational decisions. In emergency situations, the incident commander's workload can be extreme and comprise multiple uncertainties, such as conflicting meanings and values at stake, competing goals and time constraints (Lipshitz & Strauss, 1997; Rake, 2003). The incident commander usually executes his/her practices in unknowable and unpredictable contexts, and his/her assessment of uncertainties constitutes a major obstacle to effective decision-making (Boehm, 2017). Since situational awareness is a task privileged to the incident commander, the consequences of ineffective decisions can be costly, and the fire department's response to potential tunnel fires might perhaps be strengthened by a structure that also involves the members of the firefighting team in the decision-making process.

The main tasks that fire and rescue personnel engage in during tunnel fire response operations concern outlining strategies, choosing tactics and performing hazard mitigation work effectively (Njå, 1998; Sommer & Njå, 2011). For some of the informants, it was difficult to understand the logic behind their strategies and response tactics. Hence, their answers were assessed as critical deviations from the taught practice. The events presented typically included multiple dilemmas and uncertainties, and the informants were asked to prioritize different choices of action against each other. When arriving at the incident scene, some informants prioritized starting search and rescue for people downstream in the tunnel, rather than providing first aid to victims in close vicinity or initiating extinguishing of the fire. However, in the size-up phase outside the tunnel, these informants would prioritize patient treatment. This finding is puzzling because, while health services may be present and ready to provide medical assistance for victims outside the tunnel, this will not be the case inside the tunnel. Other informants would prioritize information gathering and personal safety in the earliest phase and seek to achieve situation awareness before considering advancing towards the fire. Contrarily, at the incident scene, these informants downsized issues related to personal safety and chose to start extinguishing the fire or to search for people, rather than gathering information about vehicles and people downstream in the tunnel.

It is well known that tunnel fires involving HGV represent difficult and dangerous situations for fire and rescue personnel. The fire can spread rapidly to other vehicles, road users can be trapped in the tunnel and personnel must continuously conduct risk assessments to monitor and update the state of the work environment. In line with the literature, situation awareness is a continuous monitoring of the environment, noticing what is going on and detecting changes in the environment (Endsley, 2006; Flin et al., 2008). Hence, it is important that personnel prioritize information gathering through all phases of the emergency response.

How uncertainties related to major tunnel fire events should be comprehended and which strategies and tactics should be prioritized in the different phases of the emergency response varied substantially amongst the informants. In general, it seems that informants did not share the same understanding of the presented events. The enacted practices were characterized by conflicting interpretations of critical factors that should be assessed and the associated risk and uncertainties. For instance, some informants were primarily preoccupied with activities meant to ensure optimal premises for combating the fire, while others were more concerned with conditions affecting road users' health and safety.

A fire department's response to major tunnel fire is a result of the firefighting team working together and not the individual firefighter's work in isolation. Hence, the outcome of an emergency response is to a large degree dependent on shared situation awareness and shared understanding of which activities should be prioritized to achieve the overall goal. Few informants showed circumstantially specific judgments when stating concerns and actions for responding to the presented cases, and the majority tended to rely on preplanned response plans. For competent practitioners, problems are not presented as given facts but, rather, constructed from situational cues which are puzzling, troubling and uncertain (Schön, 1991). Once the problems are constructed, boundaries for attention are set, and problems are solved by application of a certain kind of behaviour which usually is tailored to the unique requirements of the situation. Thus, flexibility to solve problems in future and unknown situations is of major importance to identify anomalies and ascribe meaning from situational cues (Endsley, 1995;

Illeris, 2009, 2010). Previous research has shown that incident commanders pay attention to details rather than considering the overall picture of the situation and often end up behaving reactively instead of proactively (Rake & Njå, 2009).

Adequate responses during emergency situations in tunnels require personnel capable of providing judgements and decisions inherent in the situation and that at times may exceed the standard response practices. While it might be beneficial to design learning activities that incorporate the established routines and procedures, the fire department might also benefit from learning activities that encourage personnel to reflect upon aspects of their practice.

First responders' tunnel fire safety competence is in some way reflected in the unclear understanding and the diverse strategies and tactics that informants chose to engage in. A fundamental challenge associated with the large variety of enacted response practices is that there may be great uncertainty related to the fire department's response to a major tunnel fire. Self-rescue is the core principle in the event of a tunnel fire and sets expectations for road users' evacuation behaviour. Evacuation is a complex issue, and the outcome is contingent on individual and structural preparedness (Njå & Kuran, 2015). The ability of the personnel to carry out effective rescue work is partially constrained by the tunnel's design (i.e., subsea, long, single-tube, steep slope) and by physical prerequisites (i.e., firefighters' physical condition, availability of resources, durability of breathing air). Ensuring premises for a rapid and safe evacuation of road users in the initiating phase of a tunnel fire is therefore decisive for the outcome of the response operation.

The tunnel's emergency response plans are based on a predefined ventilation strategy, which creates a dilemma between ensuring the safety of the personnel and that of road users. What risk should the personnel assume during response operations and which criteria should form their decisions and choices of action? A common approach amongst the informants was that of prioritizing the extinguishing of the fire to stop further smoke production and support the rescue operation. Even though previous experiences have shown that the predefined ventilation strategy has serious implications for the self-rescue principle and may affect road users' possibility of safe escape (NSIA, 2013, 2015), critical judgements questioning this philosophy were seldom reported. For

Schön (1991), skilful performance in situations of uncertainty and conflicting values at stake is materialized through a kind of reflection on patterns of action. By reflecting on their choices of action, personnel may make new sense of the situation and reconsider the established practices and understandings. When the operational goal is saving and reducing injury to human lives, the fire department might benefit from learning activities that bring discussions about how self-rescue concerns should be addressed and handled during response operations to major tunnel fires. For instance, is the predominant emergency response strategy to fires in single-tube tunnels appropriate to facilitate the best conditions for saving lives? In this learning environment, the regulations, tunnel design, traffic picture, safety systems, road users' behaviour and fire and rescue services' related response practices should be debated.

6.1.2 Competence development and learning activities

Sufficient competence in tunnel fire safety is critical for fire and rescue services involved in rescue and extinguishing operations in complex tunnel systems. The unclear and fragmented practices of fire and rescue personnel raise the need to address tunnel fire safety competence as an important aspect of the fire and rescue services' safety management system. The fire and rescue services are subject to the requirements listed in the *Regulation concerning the organization and dimensioning of the fire and rescue services and the emergency centrals* (DCP, 2022). The regulation provides a relatively detailed description of how the fire and rescue services should be organized and sets the minimum requirements for the organization and dimensioning of the emergency response preparedness. Further, it is expected that the fire and rescue services adopt a risk-based approach and carry out risk and vulnerability analysis to adapt their response capability in the best possible way to the tasks they are likely to meet. Based on results from the analysis, it is further expected that competence-enhancing activities are organized to ensure sufficient capability amongst the personnel. From an overall safety management perspective, the fire and rescue services' emergency response preparedness may be perceived as a subsystem designed to interact with the tunnel system. In this interaction, road users' safety should be at the forefront. Understanding and facilitating adequate response capability in future situations requires a proactive safety

management approach to competence. Nancy Leveson's (2004, 2011) system safety theory is relevant for dealing with the issue of competence development within the fire and rescue services.

Systems theory treats safety as an emerging property of a hierarchical structure of subsystems where each level applies constraints to enforce the desired behaviour upon the level beneath (Leveson, 2004, 2011). A main focus is the engineering of the system to prevent accidents through activities that are subject to feedback loops of information and control. The responsibility to develop competence within the fire and rescue services is shared by a large number of actors at several hierarchical levels, ranging from the authorities at the top to the individual firefighter at the bottom (Bjørnsen & Njå, 2019). Hence, tunnel fire safety competence must be determined and taken into account at all hierarchical levels, including the directorates, the municipalities and the local fire departments with their related personnel. However, in practice, the primary responsibility for developing competence and ensuring sufficient emergency response preparedness in tunnel fires rests with the local fire department. The laws and regulations enacted by the authorities represent constraints for the level beneath and set the premises for the development of guidelines, standards, competence requirements, curricula and learning activities. Tunnel fire safety competence is not addressed explicitly by the regulations, and the various agencies have not established recognized safety constraints that enable the fire and rescue services to define necessary levels of competence. From a systems theory perspective, where safety management is inherent in effective control mechanisms and proactive measures, the regulative regime seems to be somewhat inadequate when it comes to establishing a framework that facilitates tunnel fire safety competence development.

In this enforced self-regulation regime, tunnel fire safety competence development and learning efforts are often viewed as voluntary. Experiences have shown that these efforts are driven by the local fire department's interest and usually constrained by insufficient pedagogical resources and economic considerations. Self-regulation requires that decision-makers recognize and are aware of the risks related to major tunnel fires. It could be claimed that decision-makers are influenced by the regulative framework and that their incentives are often restricted to satisfying the requirements imposed by the regulation. To a certain

extent, the fire and rescue services tend to approach safety management based on a compliance perspective instead of a proactive perspective, as is expected. Further, the absence of tunnel fires with cascading events and fatalities seems to generate a more reactive approach to tunnel fire safety.

One way to achieve a more proactive approach might be to map the current level of competence and conduct learning activities rooted in pedagogical considerations. In this system, principles, models and tools that enable the fire and rescue services to develop and monitor learning processes, evaluate the effect of learning activities and determine whether an adequate level of competence is achieved are needed. Agreement would be necessary on defining performance requirements in tunnel fire responses and criteria indicating when the individual firefighter or the firefighting team has achieved an adequate level of competence. Those responsible for designing and implementing learning activities need to understand the process of learning, the requirements for effective performance and the personnel's level of competence. Without such an understanding, tunnel fire safety might be difficult to manage effectively.

The fire and rescue services acknowledge learning activities as important to develop competence amongst the personnel and ensure that incidents in tunnels are handled successfully. The implementation of the topic *Efforts in tunnels* is an important milestone regarding tunnel fire safety competence development, as it constitutes the first mandatory learning activity addressing challenges related to response operations in tunnels (NFRA, 2019). However, the educational system has not established a framework to provide guidance and enable the fire and rescue services to develop optimal learning activities. The local fire department has a high degree of freedom to determine what the content of learning should be and which instructional techniques are best suited to achieve the learning goals. Further, the educational system has not provided any criteria for assessments of learning, and tools to evaluate whether and how learning has taken place are almost absent. Assessments of learning, if conducted, are done so and analysed in a variety of ways, and their outcomes rarely serve as input for improving learning processes or as certifying the personnel for the complex tasks of emergency response operations in tunnels. The lack of systemic evaluation and information

flow hampers the ability of the fire and rescue services to uncover weaknesses and correct potential deviations. Without a feedback control structure, it is also unclear how actors at each level of the hierarchy acquire reliable knowledge about the current state of the system and build their understanding. One way to approach this issue is to designate learning agents responsible for facilitating learning processes and ensuring that the fire and rescue services engage in effective learning and adopt a more committed approach to competence development.

Some fire and rescue services responsible for tunnels at risk acknowledge tunnel fire safety as an area of current improvement and have engaged in the development of more comprehensive learning activities. For those fire and rescue services, the implementation of the topic *Efforts in tunnels* seems to have a minor impact on enhancing personnel's competence in tunnel fire safety. The curriculum dedicates only two hours to the topic, and the learning outcomes are defined as simple levels of cognition expected to be reflected through learners' ability to remember and recognize specific facts, methods or conditions related to incidents in tunnels (NFRA, 2019). Additionally, the specific aspects of learning within the fire and rescue services are not captured. In general, compared to the learning activities developed by the local fire departments, the topic only treats superficially the complexity and challenges encountered in tunnel fires. In a systems' thinking framework, this example illustrates that tunnel fire safety is insufficiently managed by those responsible for developing curricula and learning activities.

6.2 Learning within the Norwegian fire and rescue services

Learning within the fire and rescue services is essentially about improving performance and making sure that personnel choose adequate strategies and tactics in emergency responses. Learning is mainly experienced-based, involves on-the-job training and consists of a range of activities: from formalized learning activities (i.e., lectures, training exercises, educational programmes) to informal learning activities (i.e., responses to incidents, activities between responses, evaluations of responses, discussions during gatherings).

While learning within the Norwegian fire and rescue services is approached from different perspectives, this study has shown that aspects of the two approaches to learning (i.e., the individual cognitive approach and the socio-cultural approach) need to be considered together to understand how fire and rescue personnel learn (Braut & Njå, 2009; Illeris, 2010; Njå & Braut, 2010; Sfard, 1998; Sommer et al., 2013). For instance, for fire and rescue personnel to learn from different kinds of learning activities, the knowledge and skills to be learned must be absorbed through an internal psychological process of elaboration and acquisition. The acquisition of knowledge and skills takes place as a combination of exposure to new stimuli during learning situations and the personnel's prior knowledge and experiences (i.e., results from prior learning). In this process, knowledge is constructed progressively through adaptive mechanisms of accommodation (i.e., the individual adjusts to the environment) and assimilation (the environment is adjusted to suit the individual) (Illeris, 2003, 2010).

In this study, the need for personal experience and critical reflection was evident for meaningful learning (Bjørnsen et al., 2022). Further, the ability to engage in mental abstractions and problem-solving during learning activities was emphasized by the personnel as being highly valuable to achieve learning (Bjørnsen & Njå, 2023). For instance, the pilot course had an emphasis on structured group discussions and decision-making and response in real-life situations in an atmosphere where creativity and openness was encouraged. Most participants expressed that physical role-play exercises, followed by analytical sessions presenting hypothetical tunnel fire events that increased in complexity (i.e., table-top exercises), where their experiences and response practices were discussed, enabled effective learning. Therefore, one might say, in agreement with Kolb (1984), that learning within the fire and rescue services seems to be facilitated by an integrated process that entails personnel being involved actively in new experiences, reflecting on these experiences, creating new concepts and then applying these concepts as guides for decision-making and response in emergency situations.

However, the process whereby the development of knowledge and skills takes place cannot be entirely understood without observing the

interaction between the personnel and the social context in which learning occurs (Hager, 2004; Illeris, 2002, 2003; Lave & Wenger, 1991; Wenger, 1998). According to Lave and Wenger (1991), learning lies in the contextual features present in the fire department and can be described as a process of participation and interaction between colleagues. Fire and rescue personnel participate in different kinds of learning activities and continuously interact with colleagues who have more expertise. Results from the pilot course showed that learning experiences were supported by activities that stimulate collective discussions between the participants and more experienced colleagues (Bjørnsen & Njå, 2023). Solving specific problems alongside more experienced colleagues allowed participants to discuss response practices, receive guidance and feedback on their decisions and choices of action, and then construct new meaning and experiences. Further, relationships of mutual trust allowed greater disclosure, enhanced opportunities to question the enacted response practices and were therefore considered crucial in the learning process. In this way, personnel are socialized into the culture and practices of the fire department, and the relationships and interactions that take place are essential for learning. This mode of learning, which includes participation and discussions, is extremely important for learning the knowledge and skills that underpin routines and work practices present in the fire department (Eraut, 2004a).

The point is that the two approaches to learning complement each other and must be considered concurrently to understand learning within the fire and rescue services. The individual cognitive approach sees learning as a process of active cognitive reorganization and focuses on the psychological mechanisms involved when fire and rescue personnel acquire knowledge and skills. The socio-cultural approach, on the contrary, sees learning as a process of enculturation into work practices and focuses on the social relations and interactions between personnel. Consequently, fire and rescue services should explore ways of coordinating cognitive constructivist and socio-cultural aspects of learning into educational programmes and learning activities.

6.2.1 The learning model

This study has investigated Sommer et al.'s (2013) model of learning in emergency response work (cf. Figure 5) and shown that the model may be used to explain learning within the fire and rescue services. Results confirmed the theoretical model and indicated that the process of learning is influenced by the *content* of what is being learned, the *context* in which learning takes place, fire and rescue personnel's *commitment* to learning activities, involvement *decision-making and response* and *reflection* (Bjørnsen et al., 2022). Learning outcomes may be categorized as *change*, c*onfirmation* and/or *comprehension*. Accordingly, learning within the fire and rescue services may be understood as changing the personnel's behaviours, confirming behaviours that are functional and providing deeper comprehension of the complex systems and behaviours addressed.

For learning to occur, the individual firefighter needs to be open and motivated to acquire new knowledge and experiences. New knowledge and experiences by themselves may have no meaning to the individual, and the opening for learning stems from the individual's interpretation and understanding of these. Thus, the content, context and commitment (i.e., stimuli situations) need to facilitate creation of meaning within the individual. More precisely, the individual needs to experience the content of learning as relevant to his/her occupational tasks and responsibilities, the context in which learning takes place needs to be experienced as realistic and he/she needs to be actively involved (i.e., physically and mentally) in the learning process. Furthermore, these stimuli situations need to enable decision-making and response either as active behaviour in a real context or as mental simulations. However, for the individual firefighter to achieve learning, he/she needs to reflect upon the performance and suitability of the decisions made and actions taken.

The structural model considered reflection to have a central position in the learning process and hypothesized that the effect of content, context, commitment and decision-making and response on the outcome of learning is indirect and mediated through reflection. Drawing upon the literature, the rationale was that, through reflection, fire and rescue personnel go beyond the immediacy of the concrete experience, explore their decisions and response practices and encounter different

perspectives that generate new insights and possibilities for approaching emergency situations (e.g., Boud et al., 1996; Brookfield, 1998). In line with Sommer et al.'s (2013) model of learning, results indicated that reflection has the strongest impact on the outcome of learning. However, the most striking finding was that, while the effect of content and commitment on the outcome of learning was mediated through reflection, the effect of context and decision-making and response on the outcome of learning was direct and insignificantly related to reflection.

A possible explanation is the quality and accuracy of the constructs measuring the context of learning and fire and rescue personnel's involvement in decision-making and response. For instance, it seems that the construct measuring the context of learning captures the instructional techniques used by the fire and rescue services in different learning contexts and that the construct measuring fire and rescue personnel's involvement in decision-making and response captures experiences with incidents in tunnels and, thus, relates only indirectly to decision-making and response. Since the evaluated model shows a good fit with the data, we assumed that the measured constructs might provide additional dimensions to Sommer et al.'s (2013) model of learning in emergency response work. Consequently, further empirical testing of the learning model is required, with possible inclusion of new dimensions, i.e., experiences with incidents and specific instructional techniques. Additionally, further research might consider the development of an instrument that seeks to capture the observable performance (i.e., decision-making and response) of fire and rescue personnel in emergency response and training situations and the contextual features of learning. While the contextual features might be captured through operationalizing socio-cultural aspects of learning, i.e., relationships and interactions between the personnel (Lave & Wenger, 1991; Wenger, 1998), decision-making and response in emergency response work might be captured through emphasizing aspects of the NDM framework, i.e., information processing, situation awareness (Klein, 2015).

6.2.2 Learning practices

Working with experiences is crucial to achieve learning. Results from this study have demonstrated the importance of reflection in the learning process (Bjørnsen et al., 2022). The benefit of reflection is to give the

opportunity to think about a concrete experience, assess what happened, evaluate decisions and responses, and subsequently develop more comprehensive understanding (Boud et al., 1996; Brookfield, 1998; Kolb, 1984; Schön, 1991). Current learning practices within the fire and rescue services are focused on developing personnel's basic knowledge and skills, which are necessary for becoming a member of the firefighting team. However, the value of reflection seems to be underestimated in learning situations, and reflective activities are mostly incorporated in debriefing sessions after practical training exercises. The debriefing sessions lack a particular structure and are usually organized through questions encouraging participants to describe their experiences and account for actions taken during the exercises. The purpose of the debriefing is to provide participants with the opportunity to step back from the accumulated experiences and reflect upon their decisions and choices of action in a critical way. Hence, stimulating reflection from experiences is more than simply getting the participants to describe events or account for actions taken. The emphasis should be on creating a series of learning experiences and encouraging reflection through debriefings by using different kinds of questions and techniques that link the experiences and reflection in different ways. Thus, to enhance learning outcomes, carefully structured debriefings with clear analytic lessons should be designed and managed by instructors equipped with pedagogical competence.

To ensure learning from emergency responses, the fire and rescue services are required to evaluate their performance, identify learning points and implement them in the organization (DCP, 2022). Evaluation of responses is necessary if one is to challenge the rationale behind the current work practices. By critically analysing responses and questioning the established knowledge and practices, personnel might be able to gain new knowledge and skills, and their understanding might be changed, confirmed or strengthened. Practices for evaluating responses from incidents are conducted in a variety of ways, depending on the personnel involved in the evaluation process. Further, the personnel conducting the evaluation process lack critical voices challenging the appropriateness of the response, as they are most often involved in the incident themselves. It appears that the social climate within the fire and rescue services is more about preserving employees' self-esteem without exposing them to

criticism, even in constructive terms. To allow personnel to achieve their full learning potential, the fire and rescue services need a culture that allows critical reflection upon performance, daring to admit errors, as learning and development are in focus and not the assignment of blame. In a society of increased complexity with high competence requirements, those involved in curriculum design, teaching and learning should emphasize learning activities that underpin methods that promote and guide fire and rescue personnel's reflection.

In line with principles of design science, the method for developing the pilot course for incident commanders was mainly focused on *building* and *evaluating* a new artefact (March & Smith, 1995). Designing learning activities is about finding innovative solutions to meet the needs and problems the fire and rescue services face in tunnel fire responses; it requires knowledge about the mechanisms enhancing learning. To ensure theoretical anchoring and significant learning mechanisms, each of the learning model's elements (cf. Figure 5) was addressed explicitly in the design of the course and combined with practical experience from the local fire department (Bjørnsen & Njå, 2023). While it is important to have a clear understanding of important aspects that facilitate the process of learning within the fire and rescue services, instructors have an essential role in integrating these aspects in the best possible manner into the learning process. Apart from having good knowledge of the subject matter, they must be able to determine learning goals for the participating group and which instructional techniques are best suited to achieve these goals. This requires an understanding of learning processes and techniques that stimulate problem-solving, creativity and reflection.

Currently, the fire and rescue services have not established any specific requirements to ensure necessary pedagogical competence amongst instructors. Too often, instructors lack familiarity with didactical principles and how to approach learning and competence development. The current practice for selecting instructors is based on practical experience and personal interest related to the subject area to be taught. Thus, in many cases, the design of learning activities is primarily influenced by the existing expertise within the local fire department, and the assumptions on which learning activities are based are barely questioned. For instance, a common understanding is that theory is the preserve of the academic domain and practice that of the practitioners.

As fire and rescue personnel regard themselves as practitioners, the value of theoretical knowledge is underestimated, and great emphasis is placed on disseminating practice-based experience. The worth and contributions from practice-based experience to vocational expertise have long been acknowledged as having a great value (Billett, 2010), and the personnel learn a great deal of their knowledge and skills through practice (Sommer, 2015). However, to improve the outcome of learning and enhance personnel's competence, both theoretical and practical knowledge should be integrated into learning activities in ways that are relevant and meaningful to participants. Such integration is valuable and might help the fire and rescue services to better understand the practical value of learning theoretical concepts, facts and principles.

6.3 Contributions of the research

This thesis contributes to new knowledge, mostly in the research field of learning and competence development within the fire and rescue services, with special attention paid to tunnel fire safety.

A significant contribution of the research conducted for this thesis is insights into the Norwegian fire and rescue service's kinds and levels of competence in tunnel fire safety. These insights have emerged from examining relationships between fire and rescue personnel's perceived and actual competence. Results show that fire and rescue personnel's perceived competence, as reported in the national survey, inaccurately reflects the actual competence required by the fire and rescue services (Bjørnsen et al., 2023).

From a practical point of view, the research is an important step to elaborating the performance of fire and rescue services as part of the overall tunnel fire safety management system. At the same time, the research provides an understanding of the knowledge and skills that may constitute fire and rescue personnel's tunnel fire safety competence. An essential part of the comparative study was to generate data on uncertainties and challenges that personnel face in major tunnel fire scenarios and how such scenarios may be understood in the current response practices. For instance, it was found that assessments of uncertainties should be considered when activating the predefined ventilation strategy and how the ventilation systems may assist self-

rescue are scarce. Such aspects must therefore be incorporated into future designs of learning activities.

From a theoretical point of view, the core outcomes of this research were to conceptualize learning and develop models that allow a better understanding of the mechanisms that influence fire and rescue personnel's learning and competence development.

As shown in this study, the model for learning in emergency response work is supported by empirical evidence and may be applied to understand learning processes within the fire and rescue services (Bjørnsen et al., 2022). The study has elaborated on previous research in emergency response work (Braut & Njå, 2009; Njå & Braut, 2010; Sommer et al., 2013) and added new knowledge about essential aspects that should be present and the importance of reflection in the learning process. Further, results from this study point to the possibility of expanding the model to include potential new dimensions.

A main finding in this study is that learning outcomes are expressed as changes in structures, behaviours, cognition and processes, confirmation of existing knowledge and practices and comprehension of established practices, tools, behaviours or working methods (Bjørnsen et al., 2022). Learning within the tunnel fire safety management system requires knowledge about whether and how learning takes place. Thus, feedback mechanisms that allow information to flow across different hierarchical levels in the emergency response system and provide information about the benefit of learning activities are a prerequisite. When assessing learning outcomes throughout this study, the evaluation tool for assessing learning effects from real event operations and cooperations exercises has proved to be a valuable analytical tool. The evaluation tool draws upon theories that illuminate not only how individuals learn and develop knowledge and skills but also how social systems affect individuals' ability to learn (Bjørnsen et al., 2020).

In contrast to other studies that have considered organizational or teams aspects in emergency response management, the research presented in this thesis combines a systems theory approach to safety with individual learning theories, thus placing the individual firefighter's competence at the centre of attention within the tunnel fire safety management system (Bjørnsen & Njå, 2019; 2020). This combination may supplement a

traditional organizational learning perspective, with an enhanced focus on the diversity of competencies of individual professionals taking part in on-scene efforts in rescue operations.

For instance, the analyses recommend a modelling framework to increase competence in tunnel fire safety, based on the development of safety constraints that the fire department could be able to monitor with tools on a continuous basis. In this way, the research shows that it is possible to think of emergency response management as processes through which individual learning and competence development become embedded in the organizational structure and advance organizational learning. Therefore, this study offers a new perspective in the field of emergency response management that should be further developed in organizations dealing with complexity in socio-technical systems.

The findings of this study have contributed to the development of a pilot course for incident commanders involved in tunnel fire safety work, as a part of a European project in the field of vocational learning and education (i.e., SAFEINTUNNELS). The design of the pilot course places great emphasis on problem-solving activities and critical reflection in an environment where group discussions and creativity are encouraged (Bjørnsen & Njå, 2023). During the development and execution of this course, it has become apparent that, in order to enhance competence in tunnel fire safety and ensure that incidents in tunnels are handled adequately, it is a prerequisite that the various emergency response agencies discuss and understand each other's perspectives and responsibilities. It is well known that collaboration outside one's own organization is challenging and has tensions related to boundaries, e.g., conflicting perspectives, priorities of tasks and differences between practices (Andersson & Lindström, 2017). Hence, interagency collaboration across organizational boundaries has been acknowledged as a critical factor for the success of the emergency response and therefore has been implemented in the final course.

6.4 Assessment of the research quality

The reliability, validity and trustworthiness of the data are important issues related to assessment of the research quality. Within the constructivist paradigm, Lincoln and Guba (1985) propose four

trustworthiness criteria as desirable for assessing the quality of the research: *credibility*, *transferability*, *dependability* and *confirmability*.

Credibility refers to the strength of the research findings and whether these findings represent plausible information that is credible and a correct interpretation of them by the researcher (Lincoln & Guba, 1985). To operationalize credibility, techniques such as prolonged engagement, persistent observation, triangulation of data sources, peer debriefing and negative case analysis were adopted. My prolonged presence in the fire department, combined with my role and involvement in the SAFEINTUNNELS project, enabled me to invest sufficient time in activities that allowed me to examine learning practices, become familiar with the employees in their natural working environment and learn about the contextual and cultural conditions. Throughout the four years, I attended several activities to understand the actions and interactions of the employees and how tunnel fire safety is approached by the fire department. During the research project, I gradually came to know many of the people that I interacted with and established a bond of trust with the employees. It seems that, by taking time to become acquainted with the fire department and understand the prevailing tunnel fire safety practices, I succeeded in gaining the trust of several employees and in being accepted as one of them.

The research initially started with observation of tunnel fire safety activities and meetings with experts/mentors possessing thorough knowledge and experience about practices expected to support learning and competence development. These observations and meetings were followed up with discussions to provide additional information, verify the obtained data and clarify misunderstandings. Through these discussions, I could test whether my findings were meaningful for them. Mostly they were, even though at times they had different opinions, and my initial interpretations were refined (negative case analysis). Hence, I consider potential distortion of information and researcher bias to have been reduced. Additionally, in this period, documents concerning the fire department's tunnel fire response philosophy (i.e., object plans, emergency response plans, procedures, action plans, teaching material) were acquired. These documents were important and provided opportunities for capturing expectations of tunnel fire response strategies

and facilitated my inferences and the analysis of actual competence amongst first responders.

Since objective reality can never be fully captured (Denzin & Lincoln, 2011), methodological triangulation was used to obtain a more comprehensive understanding of the research questions, add richness to the data analysis and avoid premature conclusions. Triangulation is defined as *"the combination of methodologies in the study of the same phenomenon"* (Denzin, 2009, p. 297) and is a technique used to facilitate the validation of data or results through cross verification from different sources. Triangulation in method was done by conducting participant observation, a questionnaire, a comparative study and a pilot course as tools to clarify meaning or verify my observations and interpretations. The different types of data that were acquired showed different aspects of tunnel fire safety learning practices and competence within the fire and rescue services. For instance, results from the questionnaire and the comparative study provided insight into fire and rescue personnel's competence from two different perspectives. Furthermore, results from the questionnaire and the pilot course provided evidence and additional information of the essential aspects that need to be considered to understand and facilitate learning processes within the fire and rescue services.

The model of learning in emergency response work was analysed with latent factor constructs, which represented measurement scales constructed by the researcher and subsequently assumed to be directly observed in a real-world context. A pivotal point lies in the accuracy of researchers' inferences regarding their understanding of the measured constructs and the dimensions they are meant to capture. This is a crucial point of validity, since it implies abstract entities (Kvale, 1995). During the research work, the issue of the accuracy of the measured constructs was considered, and attempts were made to collect as reliable data as possible. The current work relies heavily on theoretical underpinnings reflecting different facets of workplace learning. However, it should not be overlooked that the conceptual structures that constitute meaning are partly a result of subjective interpretation and not entities that could be used alternatively by different researchers. It is therefore important to think of the accuracy of the items capturing the different dimensions of

the learning model and whether or not these items measure what they are intended to measure.

Another technique to establish credibility of the research findings was the use of peer debriefing. Peer debriefing allows a qualified peer to assess whether or not key points are missed, meanings explored and the basis for interpretations clarified (Lincoln & Guba, 1985). Throughout the research period, data and findings were frequently discussed with supervisors, co-authors and fellow PhD students. Additionally, all papers have been subject to external evaluation from reviewers in internationally recognized journals.

Transferability refers to findings that can be applied to other settings or groups (Lincoln & Guba, 1985). To ensure transferability, the researcher must present detailed data descriptions of the context studied, so that others can draw their own interpretations about whether the findings and results are transferable. To enhance the degree to which the results may be applied in other contexts, it was essential to provide descriptions capturing the essential learning mechanisms within the fire and rescue services and the personnel's kinds and levels of competence in tunnel fire safety. The mixed methods approach and various sources of data used in this study enabled me to provide detailed and descriptive data of the studied topic and the central assumptions underlying the analysis. Through the research activities, I found that some of the challenges and issues discussed in this study also exist in the context of other emergency response services and other countries (SAFEINTUNNELS project). Since Norway is a country with a high number and a large variety of tunnels, it is reasonable to assume that findings from this study may also be applied to fire and rescue services in other countries.

Dependability refers to the constancy of the data over time and across researchers and methods (Lincoln & Guba, 1985). To enhance dependability, Lincoln and Guba recommend overlap in methods (triangulation), stepwise replication (repetition of data collection and analysis), and inquiry audit (external examination of the research process and findings). The use of different data collection methods enabled me to compare whether the data collected through one method corresponded to data collected by another method. For instance, through the national questionnaire, data about the essential learning mechanisms within the

fire and rescue services were acquired, which were later seen in comparison with data from the pilot course. Stepwise replication was handled during evaluation meetings with the panel that first analysed fire and rescue personnel's response strategies and priorities separately and later compared the results to establish deviations from the taught practices. The inquiry audit was, as previously mentioned, ensured through cooperation with supervisors, co-authors and fellow PhD students.

Confirmability refers to whether the findings represent the people that are being studied without contamination of researcher bias (Lincoln & Guba, 1985). The major technique to address this issue is the use of confirmability audit, i.e., methodological reflections combined with external examination. During this research study, I have constantly reflected on the methodological approaches, documenting stepwise the research process and discussing the research findings with others. However, a clear challenge caused by my prolonged engagement in the fire department was the danger of 'going native'. *The longer the investigator is in the field, the more accepted he or she becomes, the more appreciative of local culture, the greater the likelihood that professional judgments will be influenced* (Lincoln & Guba, 1985, p. 304). Throughout the research, I was aware that I could tend to identify too much with the employees, become detached from the researcher perspective and lose 'objectivity'. Awareness of this aspect was a helpful step towards prevention and helped me maintain a certain distance between the people that I studied and me as a researcher. Additionally, the analyses of the data were conducted at my office at the university, enabling me to achieve some distance from the fire department and reflect on the acquired data and experiences.

My approach to the main research issue and the research questions can be characterized as both explorative and normative. The MMR approach has allowed analyses of learning and competence from different perspectives. However, a challenge with this study has been the lack of consensus related to measurable outputs that capture tunnel fire safety learning and competence within the fire and rescue services. Furthermore, a formal validation of the questionnaire has not been performed and the data collecting process has been time demanding. Also, the target group for the questionnaire was approached through the

fire and rescue chiefs, and the ultimate decision of who should participate in this study was left to them. Thus, it is reasonable to assume that the questionnaire was sent to experienced and well-informed personnel and that participation from a more random sample would have shown a different picture of fire and rescue personnel's kinds and levels of competence.

The emphasis in this study has been on studying learning processes at the individual level, while learning processes at the organizational and/or societal levels have been treated superficially. Studying learning processes in larger units would have provided additional knowledge about the essential mechanisms that contribute to learning and competence development within the fire and rescue services. For instance, considering that tunnel fire responses are a result of the tunnel fire safety management system, it would have been interesting to study how organizational learning influences tunnel fire responses. However, organizational learning has not been the scope of this thesis and remains to be studied in new research projects.

7 Concluding remarks

This chapter provides a short summary of important results and suggestions for future research on learning and competence development within the fire and rescue services.

7.1 Learning and competence within the fire and rescue services

This study was motivated by an interest in understanding learning processes within the fire and rescue services and enhancing fire and rescue personnel's competence in tunnel fire safety. The major aim has been to investigate principles, models and tools that can be adopted and implemented to facilitate learning.

When considering tunnels as special risk objects and the challenges encountered by personnel during emergency response operations in tunnels, the fire and rescue services should provide opportunities for the personnel to participate in a mix of learning activities. The learning activities should be facilitated in formal educational settings at the NFRA, as well as through internal learning activities at the local fire department.

Overall, the study has highlighted that tunnel fire safety learning and competence development should be approached by combining characteristics of the individual cognitive approach (i.e., learning as acquisition of knowledge) and the socio-cultural approach (i.e., learning as participation in the social system).

In this understanding, learning outcomes materialize following two different processes: 1) an internal mental process of acquisition and elaboration, in which new knowledge is accumulated, combined and gradually refined through critical thinking, and 2) an external process of interaction and participation in work-related activities under the guidance of more experienced colleagues. Hence, learning activities and educational programmes should be designed by systematically bringing together aspects of these two approaches.

The papers in this study address a tool to assess learning processes, the current educational framework and learning activities, fire and rescue personnel's kinds and levels of competence, the properties of a theoretical model for learning in emergency response work, and the design of learning activities. The research questions may be briefly summarized in the following picture:

When it comes to the issue of how the current educational framework and learning activities approach learning and competence, it was found that the current tunnel fire safety learning activities have developed without necessarily being exposed to assessments that stipulate the foundational principles of learning within the fire and rescue services (Bjørnsen & Njå, 2019, 2020). More specifically, the research has identified that the fire and rescue services have a high degree of freedom to develop and implement learning activities and that the frame conditions for designing effective learning systems are not in place. Additionally, monitoring tools and feedback mechanisms providing information on the performance of learning activities are almost absent. The evaluation tool developed in this study suggests that learning outcomes are expressions of change, conformation and/or comprehension and must be identified on different levels in organizations, from the individual level up to the level where regulations and standards are developed (Bjørnsen et al., 2020). The enforced self-regulation regime and the high degree of freedom allocated to the fire departments when developing learning activities generate different conceptualizations of learning. Considering tunnels as special risk objects and that the fire department's approach to tunnel fire safety learning and competence is primarily influenced by risk awareness, economic resources, pedagogical competence and the type of knowledge existing in the fire department, this is a major challenge.

Research into fire and rescue personnel's tunnel fire safety competence showed that their kinds and levels of competence vary significantly (Bjørnsen et al., 2023). The analysis indicated that personnel regard the standard of their tunnel fire safety competence as relatively high. Furthermore, a major finding has shown a discrepancy between personnel's self-evaluations of competence and the actual level of competence within the Norwegian fire and rescue services. In the event of a tunnel fire, it is crucial that personnel are able to understand the

peculiarity of the situation, make sense of relevant situational cues and then classify them appropriately, to implement adequate response actions. Results from the qualitative analysis revealed that only a few informants showed judgements that went beyond established procedures in choosing strategies to combat major tunnel fire scenarios. Moreover, situational assessments incorporating creative problem-solving skills to uncover risk and uncertainties were seldom described.

Designing learning activities requires careful pedagogical consideration of what, why and how learning occurs. Finding the right balance between different aspects of learning and integrating these into workplace learning activities is a challenging task for instructors and practitioners. Results from the quantitative analysis confirm the theoretical model for learning in emergency response work and suggest that the process of learning within the fire and rescue services is influenced by the content of learning, the context in which learning takes place, learners' commitment to learning activities, involvement in decision-making and responses and reflection are significant mechanisms to facilitate the process of learning within the fire and rescue services (Bjørnsen et al., 2022). In addition, the results reveal reflection to be the strongest predictor on the outcome of the learning process (i.e., change, confirmation and/or comprehension).

Developing capacities and preparing personnel for future emergency situations is a key issue for fire and rescue services involved in tunnel fire responses. Each tunnel fire has its unique features and characteristics, and personnel must deal with these as they are encountered. In this sense, the design of learning activities should place considerable emphasis on developing decision-making skills and problem-solving abilities, so that the personnel are able to carry out assessments of uncertainties and prioritize among different choices of actions during tunnel fire responses (Bjørnsen & Njå, 2023). Experiences from the pilot course have shown that learning and competence development derive not from abstract thought or from thinking and acting uncritically but, rather, from integrating thinking and acting through theory and practice and getting personnel to critically reflect upon their decisions and response actions. Theoretical lectures combined with role-play and table-top exercises that include both general knowledge and skills required for effective performance and the specific

challenges faced in local tunnels have proved to be useful tools to enrich fire and rescue personnel's learning outcomes and enhance competence. Working with realistic scenarios that progressively increased in complexity in groups and across experiences stimulated constructive debates and discussions questioning the fire department's approach to tunnel fire safety and the prevailing tactics and strategies.

7.2 Future research

In this thesis, I have looked upon learning and competence development within the fire and rescue services as a tunnel fire safety issue. After all, learning and competence development are fundamental aspects of the tunnel fire safety management system. Given the complexity of emergency response operations in tunnels, effective performance depends on high levels of cooperation and interactions between emergency response services and across different system levels. Some work has been done with regard to pointing to links and discussing some safety management opportunities. However, it seems reasonable to suggest that interesting topics for future research should relate to closer examination of how learning principles, models and tools may be integrated into holistic tunnel fire safety management thinking. For instance, important issues to test and develop further are associated with:

- Testing whether the learning models and tools adopted and developed in this study are also relevant in the context of other emergency response services (i.e., health, police, RTC, emergency centrals). This will contribute to generating knowledge about important learning mechanisms within the tunnel fire safety emergency response system and strengthen the cooperation between emergency response services.

- Further empirical testing of the model for learning in emergency response work, with possible inclusion of two new dimensions i.e., experience with incidents in tunnels and specific instructional techniques. In addition, more research is needed into finding suitable instruments that capture emergency workers' observable performance during actual fire events and training situations, as well as the contextual aspects of learning.

- Developing a system for ensuring cooperation between educational institutions, the NFRA and the fire and rescue services. Joint efforts and collaborations amongst authorities, the fire and rescue services and academia are necessary for integrating experiences from educational institutions and vocational practice in the initial and ongoing learning of fire and rescue personnel. This may promote new guidelines and clear requirements with respect to establishing competence requirements for personnel involved in tunnel fire safety work and provide principles and methods for developing learning activities and evaluating their functionality and performance.

- Structuring learning processes within the fire and rescue services by nominating "learning coordinators". The main responsibility of such agents shall relate to ensuring factual learning from different aspects (e.g., development and implementation of learning activities, evaluation of learning activities, facilitating experiential learning). There is a need to challenge the current approach and develop more committed approaches to learning and competence development within the emergency response services.

- Studying learning at the organizational and/or societal level in relation to learning and competence development within the fire and rescue services. The emphasis of this thesis has been on studying learning at the individual level. However, the individual firefighter operates in the context of an organization, and the outcome of tunnel fire responses is highly dependent on effective collaboration between the members of the firefighting team.

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PART 2

LIST OF ARTICLES

Article I

Bjørnsen, G., Njå, O., & Braut, G.S. (2020). A tool to assess learning processes based on the cooperation principle. In J.P. Liyanage, J. Amadi-Echendu & J. Mathew, (Eds.) *Engineering assets and public infrastructures in the age of digitalisation*, pp. 87-95. Springer.

Article II

Bjørnsen, G., & Njå, O. (2019). Applying systems theory to increase competence in tunnel fire safety – Focusing on the fire and rescue services. In *Proceedings of the 29th European Safety and Reliability Conference (ESREL)*. Hannover.

Article III

Bjørnsen, G., & Njå, O. (2020). Competence constraints for fire and rescue personnel involved in tunnel fire safety as part of the tunnels' risk acceptability. In *Proceedings of the 30th European Safety and Reliability Conference and 15th Probabilistic Safety Assessment and Management Conference (ESREL2020 PSAM15)*. Venice.

Article IV

Bjørnsen, G., Billett, S., & Njå, O. (2023). First responders' perceived and actual competence in tunnel fire safety. *Fire Safety Journal*, 136, 103758.

Article V

Bjørnsen, G., Dettweiler, U., Njå, O., & Knudsen, K. (2022). Towards an understanding of learning within the Norwegian fire and rescue services – Focusing on tunnel fire safety. *Journal of Workplace Learning*, 35 (1), pp. 112-128.

Article VI

Bjørnsen, G., & Njå, O. (2023). Vocational learning of incident commanders in tunnel fire safety work. *Australian Journal of Adult Learning: Contributions of workplace experiences to adults' lifelong learning*

Article I

A Tool to Assess Learning Processes Based on the Cooperation Principle

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Applying systems theory to increase competence in tunnel fire safety – Focusing on the fire and rescue services

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Article IV

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First responders' perceived and actual competence in tunnel fire safety

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1. Introduction

Tunnel fire safety management consists of many activities and priorities, the first of which is integrating safety by developing safer concepts than single-bore bi-directional tunnels. However, other tunnel design aspects, such as length, slope, curvature and intersections, will also compromise safety. Fire prevention by, for example, careful selection of materials is the next priority. The third priority is preparedness measures, such as technical passive and active fire protection systems, and other technical safety information and management systems. The fourth priority is fire mitigation, which includes emergency response systems and road users' behaviour and responses in tunnel fires. These involve evacuation systems, fire combating systems and search and rescue systems. An overview of the design of the tunnel fire safety management system could be organized by means of the holistic systems thinking approach [1]. Consequently, the fire departments 'competence constitutes a major concern in assessments of performance and consequences of tunnel fires.

1.1. Background

Tunnels are key elements of the Norwegian road transport system. Usually, their role is to ease road traffic and reduce travel time. Although incidents in tunnels have a lower frequency than incidents on open roads, the potential consequences of accidents in tunnels are far greater [2]. These consequences include the number of potential victims, the physical and psychological impacts on road users, and major economic and infrastructure impacts. Tunnel designs and technical safety equipment, therefore, must be assessed together with the behaviour of road users (i.e., drivers and passengers) and the performance of first responders. Importantly, fires can occur several kilometres from the tunnel entrance and in challenging environments. Given that fires represent major threats to humans and infrastructure, emergencies require well-trained incident commanders and firefighters. In addition, the principle of self-rescue needs to be exercised by road users. This is a demanding task, since road users must understand emerging situations and know how to evacuate. It is paramount, therefore, to ensure optimal interaction between road users, first responders and tunnel safety systems.

There have been more than ten major fires in Norwegian tunnels over the past decade (see Table 1). Those fires and their consequences have led to concerns about road users' safety and have attracted great attention from the media and amongst experts, both nationally and internationally. The Accident Investigation Board Norway (AIBN) has investigated most of the fire events and, for some of them, have assessed the performance of the rescue activities. Findings from these investigations have consistently identified an urgent need to improve tunnels' safety equipment and the competencies of first responders [3,4,6,7].

Although, to date, no one has died from smoke inhalation or burns, many victims have sustained traumas and respiratory disorders. Respondents in Njå and Kuran's study of the 2011 fire in the Oslofjord tunnel reported that the fire and rescue personnel's decision to increase the ventilation flow towards their location during the fire significantly endangered their safety and escape capability [13]. It is important to note that Norwegian road tunnels are, in most cases, single tubes with bi-directional traffic. Moreover, the most serious fire hazards are related to subsea tunnels. These tunnels are characterized by steep slopes and are usually longer than 2 km. Such characteristics increase the risk of fires in heavy goods vehicles (HGV) [14,15]. Tunnels are complex systems [1], thereby increasing the demands on rescue personnel to understand the situation and make decisions that optimize conditions for self-rescue. Regarding the choice of ventilation strategy, there is a dilemma in balancing the safety of rescuers and that of road users. Up to now, firefighting has been given priority over ensuring the safe evacuation of all road users.

1.2. Norwegian fire and rescue services' tactics in tunnel fires

Once the fire and rescue service has arrived at the tunnel site, the orthodox approach has been to extinguish the fire as soon as possible. Rescuers need access to initiate search and rescue work for people

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Table 1
Overview of the ten major fires in Norwegian tunnels.

Year	Tunnel	Vehicle in which the fire occurred	Number of people involved	Number of vehicles inside the tunnel	Reference
2011	Oslofjord	HGV loaded with recycled paper	34	21	[3]
2013	Gudvanga	HGV	67	58	[4]
2013	Brattli	HGV loaded with 27 tons of goat cheese	–	–	[5]
2015	Skatestraum	HGV loaded with 16,500 l. of petrol	17	5	[6]
2016	Gudvanga	Bus with tourists	32	19	[7]
2016	Måbø	HGV transporting an excavator	–	–	[8]
2017	Fjærland	Road sweeper	13	7	[9]
2017	Oslofjord	HGV	–	127	[10]
2019	Gudvanga	HGV	33	–	[11]
2021	Oslofjord	HGV	–	–	[12]

trapped in the tunnel. The tunnels' emergency response plans for longitudinally ventilated single-tube bi-directional traffic tunnels are based on a predefined ventilation strategy, with the convention that the most competent fire department will lead the response operation. This means that the airflow will be at the first responders' back, regardless of where in the tunnel the fire occurred and of the road users' locations. Concerns have been expressed as to whether this ventilation strategy is best suited to meet the self-rescue principle [3,16,17]. This is because it might contribute to road users being trapped in smoke and the spread of fire to other vehicles downstream in the tunnel. The challenge is, therefore, to concurrently address both optimal premises for self-evacuation and fire-extinguishing for rapidly assisted rescue work. To date, no one has defined what adequate firefighting competence comprises and how to develop that level and kind of competence.

1.3. Research questions addressed in the study

The study described and discussed here addresses Norwegian first responders' competence in tunnel fire safety and fire responses. A previous study gathered data from key personnel working in prominent fire and rescue services. It concluded that practices regarding tunnel fire safety are unclear and fragmented, and that the emergency response personnel's kinds and levels of competence differ substantially [17]. Njå and Svela's study prompted a national survey of firefighters and other staff involved in tunnel fire safety work. The survey captures the respondents' assessments of knowledge of what they had been taught in the training manuals and their assessments of competence about responses to fires in tunnels. We refer to this as *perceived competence*. To understand more fully the current level of competence, it is necessary to compare perceived versus actual competence. Hence, we designed a detailed study to identify the presence of taught competence in a major fire department with many high-risk tunnels in its area. The fire department had a structured training programme for its firefighters. *Actual competence* refers to first responders' expressed choices of action when confronting fire events in tunnels and is reflected through the taught strategies and priorities of tunnel fire rescue work in which the informants were engaged. Our major research issues were:

- How do employees in the Norwegian fire department regard their own competence to meet major tunnel fires?
- To what extent do first responders' self-evaluations of competence reflect the actual level of competence within the Norwegian fire department?

2. Competence – a contested concept

Competence is a broad and much debated concept. The multitude of interpretations reflect distinct conceptions and, occasionally, inconsistent usage that fosters confusion amongst those seeking to achieve improved work performance [18]. The different interpretations may be attributed to the diverse epistemological assumptions. *The behaviourist/cognitivist* (i.e., rationalist) and *the constructivist* (i.e., subjectivist) assumptions [19] constitute two major distinct orientations.

2.1. Behaviourist/cognitivist and constructivist perspectives on competence

From the behaviourist/cognitivist perspective, also referred to as the rationalistic perspective, competence is viewed as a specific set of attributes, such as "capacities used to perform a certain occupation" [20]. More specifically, it is assumed that individuals who are possessing a superior set of attributes can execute their job more competently than others. For individuals to become professionally capable (i.e., competent), the literature proposes that those attributes comprise domain-specific conceptual, procedural and dispositional capacities [21]. For instance, this may relate to common understandings of what information to look for when assessing situations, appropriate choices of actions when confronting fire events, and fire and rescue personnel's tendencies to put their capabilities into action. Attributes may be considered context independent, implying that competence may materialize in a wide range of work activities (i.e., occupations). Proponents of this approach claim it is possible to compile descriptions of job activities independent of the individuals accomplishing the work tasks. Others acknowledge that particular manifestations of occupational expertise are required in specific work settings, albeit when practising the same occupation [22]. This perspective acknowledges the canonical knowledge required of people performing an occupation such as firefighting and the situation manifestations of that work [21].

The constructivist approach provides an alternative understanding of competence, considering workers and the work as a single entity arising through the lived experience of work [19,20]. Learning activities situated in everyday practice and communities of practice are considered appropriate practices to develop individuals' competencies [23,24].

These two approaches can be seen to be complementary. First responders' competence is partly viewed as a context-free set of attributes (e.g., domain-specific concepts, procedures and dispositions) that individuals bring into a certain job. However, such descriptions cannot capture whether they use these attributes, nor how they use them to achieve specific work tasks (i.e., tunnel fires). Thus, defining what constitutes competence in accomplishing a job proficiently is not context-free but rather context-dependent and usually developed in the particular circumstances of practice [22,23]. In relation to tunnel fire responses, ensuring that the operation is understood and that there is clear communication of a tactical plan constitute a main priority amongst firefighting crews. However, the complexity of the specific situation affects the extent to which these activities may receive central attention. For instance, injured people in need of immediate medical assistance will complicate the situation and demand that patient treatment is the priority. Additionally, road users' dispositions and lack of situational awareness may impede the emergency response and mean that they require rescue assistance. More specifically, road users situated upstream of the incident site may not appreciate the danger caused by the fire and choose not to evacuate the tunnel while the environmental conditions still permit a safe egress. Hence, there are situational factors that may override standard and preplanned responses and require firefighters to assess and respond to specific situations. What constitutes

their competence becomes a subject of both personal capacities and the addressing of potentially non-routine situations that sit outside the orthodox responses.

It follows then that competence is viewed neither as a characteristic of the individual nor a characteristic of the job [25]. The emphasis is on relational factors amongst workers, the tunnel system and the emerging situation, and on the competence applied to the specific problems they might encounter. Understanding these processes in fire and rescue departments is of paramount importance to form the basis of the curriculum and scope of work to address tunnel fire response competencies. We consider first responders' *actual competence* to be the taught priorities in tunnel fire safety work, occurring in the working environment, partly through the firefighters' expertise and through the characteristics of the problem and its resolution (e.g., policy, procedures, performance requirements, financial and technical resources). Thus, competence is understood as founded within the situated domain of firefighters' knowledge, and how they interpret the situation, make judgements and act situationally as first responders when confronting the actual events. In this study, the actual competence is assessed against a set of priorities generated by the response situations. We will further clarify the differences between actual and perceived competence as they are defined in this work, in section 3.2.

2.2. Decision-making and expertise in tunnel fire response operations

Tunnel fire responses are search and rescue operations in which road users' health and safety are paramount. Common to both minor and major emergencies is the need for decision-making under time pressure and circumstantial uncertainty. Uncertainty constitutes a major obstacle to successful decision-making, as it limits individuals' cognitive reasoning due to insufficient information, conflicting meanings and diffuse values represented in the available information [26]. These sources of uncertainty influence individuals' decision-making and lead to diverse coping strategies amongst those involved in tunnel fire safety management. Hence, first responders' competence extends to decision-making informed by canonical understandings and responses, mediated by accounting for situational factors.

First responders must address major uncertainties that arise from lack of situational information, insufficient understanding of fire characteristics and road users' behaviour in crisis situations, limited knowledge regarding heat release rates and smoke dispersion, etc. During tunnel fire response, it may be difficult to access the tunnel and secure detailed information about the incident site. Information gathering through the tunnels' monitoring and surveillance equipment can assist first responders to confirm or disconfirm their understandings, use the information to decide amongst different courses of action, evaluate potential responses and then identify and enact alternative response strategies. Hence, first responders' rescue and extinguishing work needs to prioritize securing an overview of the fire scene, the spread of smoke and the number of vehicles and road users in the tunnel. These factors will inter alia provide input to selecting the fire suppression strategy.

Whilst comprising sets of predetermined practices, the responses will inevitably be circumstantially specific. It follows that first responders must be able to recognize situational possibilities and limitations and after appraising uncertainties prioritize appropriate response actions [27]. claim that skilled decision-makers can be differentiated from novices based on their ability to assess the situation and identify effective solution strategies. The success of a selected response relies on the accuracy of the situational assessment, whereas inadequate decisions and choices of action are more likely to be the result of incorrect assessments. Consequently, it is important to understand how to best develop these capacities within first responders.

3. Material and methods

The study reported in this article assesses first responders' self-evaluations of competence to cope with major tunnel fires against their actual level of competence. The analytical approach comprises two separate data gathering activities: (1) a national questionnaire, providing insight into first responders' self-evaluation of competence, and (2) a detailed study conducted in a competent fire department, yielding insight into first responders' actual competence. The fire department has immediate responsibility for more than 20 tunnels and was selected for this investigation because it is perceived by other fire departments, including the authorities, to be highly competent.

3.1. Investigation 1: A national questionnaire for fire and rescue services

A questionnaire was developed to capture respondents' perceived competence regarding tunnel fire safety and responses to fires in tunnels within the respondents' regions. The instrument was developed, building on [28,29] theoretical framework of learning, the *Handbook for Exercise Planning* [30], the textbook *Firefighting Operations in Road Tunnels* [31] and discussions with tunnel experts in fire departments. Aspects of and other findings from the survey are also presented in Ref. [32]. A part of the questionnaire comprised information about respondents' education, formal training, experiences, nearby tunnels, etc. Other items contained assessments of experiences and learning activities, starting with "To what extent …", introducing a five-point Likert scale (from very low degree to very high degree).

The electronic questionnaire was distributed to a selection of fire and rescue chiefs. The data was collected from Norwegian fire and rescue departments that had tunnels longer than 1 km in their area of responsibility. The fire and rescue chiefs selected respondents in their organizations, based on the criterion that tunnel fire safety constituted a major part of the respondents' occupational tasks. Participation was voluntary and anonymous. Prior to its administration and in collaboration with representatives from a range of fire departments, the instrument was piloted on a group consisting of 16 fire and rescue personnel employed in different positions, with both academic and non-academic backgrounds. Some items were identified as problematic, and the items of the questionnaire were revised to avoid confusion about terminologies and improve clarity and meanings.

3.1.1. Participants

In all, 1936 respondents from 113 fire departments were invited. In total, 939 fire and rescue personnel from 95 fire departments responded: a response rate of 48.5%. Incomplete responses were provided by 290, with 649 fully completing the survey. Nevertheless, these incomplete responses provided valuable data about their professional preparation and work roles and were included in the analysis. For more details of the sample population, see Supplementary Materials, Table S1. Most incomplete elements were those relating to knowledge about the specific tunnels in their fire department's area of responsibility, possibly indicating that tunnel-specific knowledge might be lacking.

The sample includes 96% men and 4% women employed in full-time (61%) and part-time (39%) roles. The respondents' average age is in the 40-49-year category, with an average of 11–15 years of firefighting experience. All Norwegian counties are represented, with the highest number of respondents in the south-western part of the country. These are also the counties with the longest and the highest density of tunnels in the Norwegian road network. The respondents belong to full-time fire departments (47%), part-time fire departments with on-call duty (27%) and part-time fire departments activated on callouts (26%). Hence, the sample is broadly representative of the national firefighting workforce involved in tunnel fire safety and rescue work.

3.1.2. Measures and exploratory factor analysis

An exploratory factor analysis (EFA) was initially conducted, with principal components' extraction and direct oblimin rotation to achieve an underlying understanding of the properties and structure of respondents' tunnel fire safety knowledge. Eleven items measuring

respondents' perceived level of knowledge were subjected to this analysis with Bartlett's Test of Sphericity (0.000) and Kaiser-Meyer-Olkin (KMO) (0.86), indicating that these items are adequate for factor analysis. The analysis supported the isolation of three latent factors with eigenvalues exceeding 1, subsequently denoted as: I: *Emergency response and tunnel system knowledge*, II: *Practical tunnel condition knowledge*, and III: *Theoretical (physical and behavioural) knowledge*. Further information is provided in sections 4.1 and 4.2.

Two items were used to measure the respondents' self-evaluation of competence: "Imagine that you are called out and must respond to a major tunnel fire. Evaluate your own competence to cope with the situation" and "To what extent is your fire department competent to cope with challenges related to tunnel fire safety work?" Responses were given on a five-point Likert scale, whose range indicated: "Little competence" (1), "Some competence" (2), "Satisfactory competence" (3), "Professional" (4), "Expert" (5). Hence, patterns of quantitative analysis were sought through these measures.

3.2. Investigation 2: identifying actual competence

Investigation 2 was designed to reveal "actual" competence amongst relevant firefighting personnel. We define actual competence as: *expressed abilities to prioritize in accordance with taught practice of tunnel fire responses*. This is different from perceived competence as investigated in the survey presented above, which is defined as *the respondents' self-evaluated competence to respond to tunnel fires*.

To capture measures of actual competence, a separate qualitative investigation was conducted, in which informants described priorities and choices made in two distinct hypothetical tunnel fire cases in well-known tunnels (a 5.8-km subsea, single-tube tunnel and a 4.4-km subsea, single-tube tunnel located further away). This can be regarded as an unprepared examination situation, which coincides with actual and real tunnel fire incidents. The difference is that the examination was a controlled situation in which the respondents were given information about hypothetical fire incidents. Two major tunnel fire scenarios were developed to disclose levels of actual competence (i.e., prioritized courses of actions, strategies and tactics, expressions of uncertainties and concerns). In total, 21 courses of possible action were presented to informants, and they were requested to select a subsequent order of priorities during three chronological phases in the tunnel fire responses: i) *alarm/en-route*, ii) *arrival* and iii) *response*. The informants' priorities were reported on a scale from 1 (highest priority) to 5 (lowest priority). For each of these phases, the instrument contained seven statements. Hence, some responses were not given priority but acted as alternatives. The instrument included two open questions for which the informants were encouraged to describe their main concerns and address three activities they regarded as crucial to cope adequately with the described fire scenarios. The investigation proceeded with informants answering individually with no access to written materials. The predefined priority list was developed using the fire department's tunnel fire safety training programme that all informants had attended. This list was used as a reference to assess first responders' actual competence (see Supplementary Materials, Table S2). Actual competence is the expressed knowledge assessed against the taught practices in the informants' fire departments. The actual competence was measured in deviations from the taught practices, the size of the deviations and their criticality.

The data comprised accounts provided by 30 informants: 20 firefighters and 10 operational commanders. Amongst the informants, 26 were employed in full-time and four in part-time positions. As noted, the study was conducted in a fire department acknowledged as being exemplary and well-informed about tunnel fire safety. The two tunnels used to frame the incident scenarios are in the geographical area of the informants' responsibilities; thus, the safety systems should be well known to them. Consequently, we expected the perceived level of knowledge and competence reported in the national questionnaire to be lower than the actual level of competence reported in this fire department.

3.2.1. Contents of the scenarios

The major tunnel fire scenarios provided informants with multiple dilemmas and uncertainties. Fig. 1 is a sketch in which the resources, the accident scene and a map illustrate the context of the scenario, without revealing the specific tunnels and the fire department that the informants were given.

The first scenario contained visible flames from a large van with dense smoke development. The informants were informed that: i) the van belonged to a welding company, ii) four trucks were parked 200 m downstream from the incident scene, iii) the van driver attempted unsuccessfully to extinguish the fire, and iv) during the tunnel closing operation, several vehicles drove into the tunnel. The road traffic operators had initiated the tunnel's emergency response plan and the fire ventilation was activated in the predefined direction (towards north). We expected the informants to identify risks of explosion and fire escalation as part of the developing risk scenarios.

The second scenario comprised conflagration and smoke from a truck. The tunnel is further away than Scenario 1 from the fire department's location, with a travel time of about 17 min. The informants were informed of the following: i) the fire's location, ii) the truck driver had initiated necessary actions but was unable to extinguish the fire, iii) road traffic centre operators had initiated fire response procedures – closing the tunnel, and iv) initiating the fire ventilation in the predetermined direction. The smoke from the fire was flowing 3–3.5 km towards the tunnel opening on the north side, and the flow of smoke (8 m/s) exposed the downstream road users. The composition of the truck's load was unknown, there was a traffic jam, a foreign bus had stopped 200 m downstream from the incident site, and road traffic operators had observed about 15–20 people walking towards north. The major concern was people evacuating to the north in the tunnel, road users' reduced mobility and limited communication means (also, foreigners – i.e., not familiar with the tunnel or the self-rescue principle).

3.2.2. Analysing deviations from best tunnel fire response practices

The aim of the analysis is not to assess whether the predefined priorities are appropriate or not. These are taught during training activities. Instead, it is to assess the degree to which informants deviate from the taught practices. The statements included in the instrument were formulated as evaluation criteria for the following dimensions: i) scenario uncertainty, ii) information gathering, iii) common situational awareness, iv) lifesaving activities – patient treatment, v) facilitating self-rescue, vi) firefighters' safety, vii) clarifying response actions, viii) confirming procedures, ix) fire and rescue resources, x) response tactics and xi) communication and cooperation.

The qualitative analysis is presented in Section 4.4. The analysis group consisted of a panel of four persons (i.e., two experts from the fire department and two of the authors) assessing responses against predefined priorities. The panel counted deviations and assessed the sizes of the deviations and the criticalities for the emergency response performance. Two moderation meetings were held to discuss and agree upon the collated responses and informants' deviations for each of the evaluation criteria. Three categories of deviations were used in the qualitative analysis:

Slight and moderate deviations are those with less than three statements differing from the taught practices. *High deviation* is a definite deviation from the best practices and includes three or more statements deviating from the taught practices, albeit not judged as critical. *Severe deviation* represents critical failure in competence and was categorized as such if informants had more than three statements deviating significantly from the taught practices.

To establish quantitatively whether there are differences between first responders' self-evaluations of competence and their actual competence, descriptive statistics and one-way between groups analyses of variance (ANOVA) were used. The descriptive statistics describe the

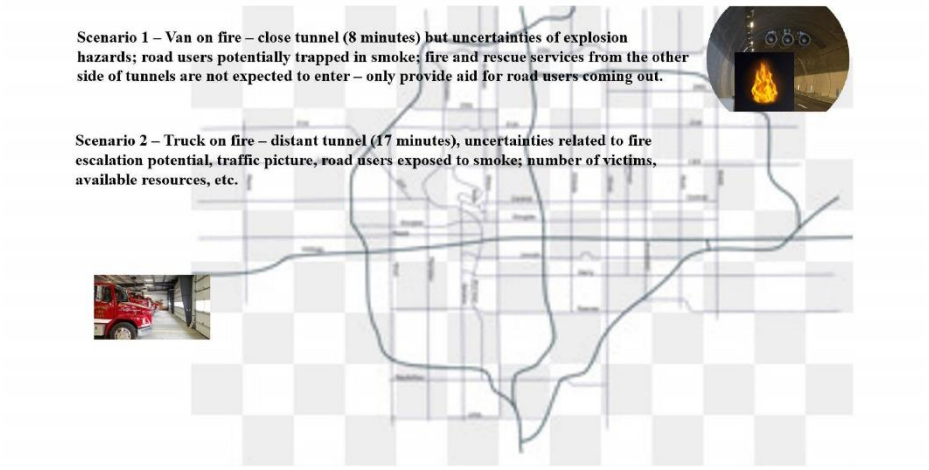

Fig. 1. The context of the scenario.

basic features of the data of perceived and actual competence. The ANOVA was used to identify differentiating patterns for first responders' perceived and actual competence. The analyses were conducted across two variables: "Employment position" and "The role related to emergency response operations".

4. Findings related to perceived and actual knowledge and competence

In this section, we present the analyses of perceived knowledge and competence across Norway, which we further illuminate by associating actual versus perceived competence in a major fire department. The local data is both quantitatively and qualitatively assessed.

4.1. Perceived knowledge of tunnel fire safety

To investigate common items that estimate the structure of respondents' self-evaluations of tunnel fire safety knowledge, the eleven items were subjected to principal components analysis (PCA). The research instrument consisted of a larger series of items, which are not addressed in this paper. Examination of the correlation matrix indicates a satisfactory degree of collinearity between the variables and that three of the items have factor loadings over 0.30 on two of the factors, implying that these items overlap slightly. The items were included in the factor with the highest loading, see Table 2, which aligns the items with these factor loadings. The extracted factors indicate that the respondents consider the statements related to knowledge of tunnel fire safety to be three distinct and independent knowledge dimensions.

The exploratory factor analysis supported the isolation of three latent constructs reflecting three distinct aspects of tunnel fire safety knowledge. Factor I - *Emergency response and tunnel system knowledge* represents the technical, operational and organizational measures intended to support efficient responses during incidents. It includes the tunnel's specific characteristics, "tailored" plans and procedures to approach incidents and analysis of available resources. Factor II - *Practical tunnel condition knowledge* indicates levels of knowledge related to the operation and maintenance of the specific tunnel's safety systems. The

Table 2
Summary of exploratory factor analysis results for self-evaluations of knowledge of tunnel fire safety (N = 657).

Items	Factor loadings			
	1	2	3	Communalities
The tunnel (s)'s distinctiveness and design	**0.84**			0.73
The tunnel (s)'s safety equipment and resource access	**0.84**			0.79
The tunnel (s)'s contingency plans and object plans	**0.77**			0.76
The tunnel (s)'s procedures and action plans for incidents	**0.63**	−0.31		0.66
The tunnel (s)'s status from inspection of tunnels		**−0.74**		0.71
Accessible resources in own fire department in the event of a major tunnel fire	**0.73**	0.38		0.66
Accessible resources in neighbouring fire department in the event of a major tunnel fire	**0.46**		0.33	0.43
Maintenance of the tunnel (s)'s safety level		**0.79**		0.85
Maintenance of the tunnel (s)'s safety equipment		**0.83**		0.82
Road users' behaviour in major tunnel fires			**0.90**	0.80
Fire dynamics in major tunnel fires			**0.79**	0.74
Proportional variance	0.67	0.79	0.77	
Total variance explained (% of variance)	50.8	12.3	9.5	
Cronbach's alpha	0.86	0.89	0.79	
Bartlett's Test of Sphericity	0.000			
Kaiser-Meyer-Olkin (KMO)	0.86			

Notes: All items are measured with the values 1 = "very low degree", 2 = "low degree", 3 = "some degree", 4 = "high degree" and 5 = "very high degree". Factor loadings <0.30 were suppressed, and factor loadings >0.40 are in bold to highlight items showing a strong correlation with the factor of interest.

functionality of the safety equipment and the barriers located in a tunnel is a prerequisite to ensure personal safety for road users and rescue personnel. Factor III - *Theoretical (physical and behavioural) knowledge* refers to knowledge of fire dynamics and human behaviours in major tunnel fires. This factor represents a comprehensive understanding of fire scenarios and possible immediate responses that enables personnel to develop risk images and improve situation awareness.

The mean level of communality, which is the proportion of variation explained by the three underlying factors, is 0.74 and indicates that the variables are well explained by the factors. Factors I and III show a high positive correlation. Hence, we might expect satisfactory self-evaluation of knowledge related to the items included in those factors. Moreover, Factor II expresses a high negative correlation, indicating lower self-evaluation of knowledge related to the items included in this factor. Additionally, this means that respondents reporting a high level of *Emergency response and tunnel system knowledge* and *Theoretical (physical and behavioural) knowledge* report a low level of *Practical tunnel condition knowledge* and vice versa. The reliability analysis showed that the Cronbach's alpha coefficients are all above 0.70, denoting that the items show good internal consistency [33]. The three-component solution captures 72.6% of the total variance within the items, illuminating aspects of the same phenomenon. Table 2 presents a summary of the EFA's findings, with the corresponding items included in the analysis of the first responders' perceived knowledge.

4.2. Descriptive statistics and analyses of variance of first responders' self-evaluation of knowledge and competence

As an initial descriptive analysis, patterns of responses were sought to identify any particular kinds of emphases. The descriptive statistics presented in Table 3 show that the respondents assess their competence as lower than the fire department's competence. However, their practical knowledge, which shall be understood as their knowledge of the specific tunnel and its condition, is significantly lower. Their opinion of their emergency response and tunnel system knowledge is significantly higher than their own assessment of competence. This means that knowledge of procedures, priorities, etc. is regarded very highly by the respondents. Their knowledge about theoretical aspects, such as fire dynamics and human behaviour, is regarded as effective and consonant with their self-evaluation of competence.

Further, we hypothesized that different groups (i.e., part-time and full-time; firefighters and leaders) amongst the respondents would vary in their self-evaluation. Consequently, we searched for any statistical significance between the variables and the factors influencing first responders' self-evaluation. The analyses indicated significant differences ($p < 0.01$ and $p < 0.001$) in the respondents' self-evaluation. The assumption of homogeneity of variances was tested and found tenable for almost all groups, using Levene's test, which tests whether the variances in scores are the same for each of the groups [33]. For those groups that violated the assumption of homogeneity, we conducted a Robust Test of Equality of Means using Welch's and Brown-Forsythe's test, to be confident that there was statistical significance between the group means. Additionally, post hoc comparisons using Tukey's test were carried out to help identify where differences in the group means occur [34]. Table 4 shows the results from the ANOVA.

Employment position differentiated significantly ($p < 0.001$) on all self-evaluations of knowledge and competence. Personnel employed in full-time positions had higher scores on all dimensions compared to part-time personnel. The greatest effects of employment position (η_p^2 = 0.10 and 0.08) were identified in self-evaluation of own competence (M = 3.02), the fire department's competence (M = 3.20) and in the theoretical knowledge dimension (M = 3.08). More specifically, the differences between the group scores indicate that personnel employed in full-time positions regard their knowledge and competence more highly than part-time personnel.

The *role related to emergency response operations* in tunnels differed significantly ($p < 0.01$ and $p < 0.001$) on all self-evaluations of knowledge and competence. Personnel in leadership roles were found to have better scores in all dimensions compared to personnel in subordinated roles. The greatest effect of employment position ($\eta_p^2 = 0.22$ and 0.21) was identified in self-evaluation of practical tunnel condition knowledge, emergency response and tunnel system knowledge. Nevertheless, the highest self-evaluations were found for emergency response and tunnel system knowledge amongst incident commanders (M = 4.00), strategic commanders (M = 3.98) and operational commanders (M = 3.62).

In sum, the greatest and most consistent differentiating patterns in first responders' self-evaluation of knowledge and competence were found for their roles in tunnel incidents (see Table 4). This indicates that we might expect to find higher levels of actual competence amongst operational commanders in the subsequent study. The differentiating patterns also give support to the idea that higher self-evaluation of competence and knowledge relates to personnel employed in full-time positions.

4.3. Descriptive statistics and analyses of variance for first responders' actual competence

As noted, the principal aim of the detailed study was to examine whether first responders' self-evaluation of competence differs from their actual competence. The analysis of the deviations between actual and perceived competence was based on the survey received from 10 operational commanders and 20 firefighters. Table 5 shows basic descriptive statistics for first responders' actual competence in tunnel fire safety. Mean and standard deviation for this sample indicate that first responders involved in tunnel fire response operations show a tendency towards approaching a high deviation of competence for

Table 3
Descriptive statistics for fire and rescue personnel's self-evaluation of knowledge and competence in tunnel fire safety. The scale: 1 = very low degree, 2 = low degree, 3 = some degree, 4 = high degree, 5 = very high degree.

Perceived knowledge and competence dimensions	Sample in the national questionnaire				
	N	M	SD	SK	KT
Own competence	656	2.78	0.92	0.46	0.50
Fire department's competence	651	2.98	1.03	0.58	0.76
Emergency response and tunnel system knowledge	654	3.31	0.73	−0.39	0.46
Practical tunnel condition knowledge	657	2.39	0.96	0.24	0.79
Theoretical knowledge	656	2.90	0.78	0.38	0.13

Notes: N = number of observations, M = mean, SD = standard deviations, SK = skewness, KT = kurtosis.

Table 4
Differentiating patterns between fire and rescue personnel's self-evaluation of knowledge and competence in tunnel fire safety.

Employment position	F	df	η_p^2	Significance
Own competence	37.87	2	0.10	0.000***
Fire department's competence	28.24	2	0.08	0.000***
Emergency response and tunnel system knowledge	7.18	2	0.02	0.001***
Practical tunnel condition knowledge	16.67	2	0.04	0.000***
Theoretical knowledge	28.46	2	0.08	0.000***
The role related to emergency response operations				
Own competence	4.87	8	0.07	0.000***
Fire department's competence	3.05	8	0.05	0.002**
Emergency response and tunnel system knowledge	15.79	8	0.21	0.000***
Practical tunnel condition knowledge	16.66	8	0.22	0.000***
Theoretical knowledge	6.61	8	0.10	0.000***

Notes: *p < 0.05; **p < 0.01; ***p < 0.001. η_p^2 partial eta squared.

Table 5
Descriptive statistics for first responders' actual competence in tunnel fire safety. Scale: 1 = no deviation, 2 = slight deviation, 3 = moderate deviation, 4 = high deviation, 5 = severe deviation.

Actual competence dimensions	Sample in the follow up study				
	N	M	SD	SK	KT
Scenario uncertainty	30	3.53	0.81	−0.51	−0.25
Information gathering	30	2.96	0.85	0.42	−0.59
Common situational awareness	30	2.43	0.77	1.43	3.19
Lifesaving activities – patient treatment	30	3.66	1.12	−0.21	−1.31
Facilitating self-rescue	30	3.43	1.04	−0.59	−0.43
Firefighters' safety	30	1.56	0.97	1.49	0.91
Clarifying response actions	30	2.03	0.66	0.70	1.78
Confirming procedures	30	3.36	0.99	0.06	−1.01
Fire and rescue resources	30	2.30	1.05	0.28	−1.06
Response tactics	20	2.80	1.60	−0.14	−1.92
Communication and cooperation	10	2.60	0.69	0.78	−0.14

Notes: N — number of observations, M — mean, SD — standard deviations, SK — skewness, KT = kurtosis.

aspects concerning scenario uncertainty, lifesaving activities – patient treatment, facilitating self-rescue and confirming procedures. A similar pattern is found in the skew values (SK), showing that more scores are clustered at high deviations for the aspects concerning scenario uncertainty, life-saving activities – patient treatment, facilitating self-rescue and response tactics. Moreover, eight of the items have a negative value of kurtosis (KT), indicating light-tailed distributions with relatively few outliers drawn towards slight deviations. We note that the mean values with slightest deviations are found for activities that are meant to enhance the endurance of the response operation and provide structure and instructions to the firefighting team.

An ANOVA procedure was employed to draw inferences concerning differences in the mean scores of first responders' actual competence across two different groups (i.e., firefighters and operational commanders). Since two of the dimensions only applied to one of the groups (i.e., response tactics and cooperation and collaboration), these were not included in the analysis. Based on previous findings, we expected considerably fewer deviations of competence amongst operational commanders and personnel employed in full-time positions. However, the analyses revealed that first responders' employment position was not statistically significant, at $p < 0.05$, for any of the competence dimensions. The role in emergency response operations showed significant differences ($p < 0.05$, $p < 0.01$ and $p < 0.001$) in only three of the observed dimensions (Table 6).

ANOVA showed that *The role related to emergency response operations* differentiated significantly on common situational awareness $F(1, 28) = 6.48$, $p = 0.017$, facilitating self-rescue $F(1, 28) = 6.64$, $p = 0.015$ and confirming procedures $F(1, 28) = 8.37$, $p = 0.008$. More specifically, firefighters were found to have fewer deviations on common situational awareness ($M = 2.20$ and $M = 2.90$), compared to operational commanders. Furthermore, firefighters were found to have higher deviations on facilitating self-rescue ($M = 3.75$ and $M = 2.80$) and confirming procedures ($M = 3.70$ and $M = 2.70$), compared to operational commanders. The greatest interaction effects were identified in confirming procedures ($\eta_p^2 = 0.23$). These findings suggest that personnel in leading positions might only possess higher levels of actual competence for aspects concerning facilitating self-rescue and confirming procedures.

Table 6
Differentiating patterns between first responders' actual competence in tunnel fire safety.

The role related to emergency response operations	F	df	η_p^2	Significance
Scenario uncertainty	0.38	1	0.01	0.538
Information gathering	0.08	1	0.00	0.767
Common situational awareness	6.48	1	0.18	0.017*
Lifesaving activities – patient safety	0.01	1	0.00	0.911
Facilitating self-rescue	6.64	1	0.19	0.015*
Firefighters' safety	2.22	1	0.07	0.147
Clarifying response actions	0.03	1	0.00	0.851
Confirming procedures	8.37	1	0.23	0.007**
Fire and rescue resources	0.16	1	0.37	0.691

Notes: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

4.4. Typical features and trends based on the qualitative study of factual versus perceived knowledge

In this section, an overview is provided of the identified trends in the deviations from each of the eleven concepts that were introduced in 3.2.2. Of the 30 informants, the number of deviations varied from 16 to 27. Individually, these numbers are not explanatory but, collectively, indicate tendencies seen in their approach. In this qualitative analysis, each of the eleven tasks or features has been considered, to draw out inferences about the issues assessed. Each of these is briefly discussed below.

4.4.1. Scenario uncertainty

Scenario uncertainty – that is the extent of uncertainty that the informants identified – has been analysed based on an assessment of the responses to the open questions. We expected to find risk identifications and considerations based on deliberations related to uncertainty of: fire substances, explosion potential, fire escalation, smoke dispersion, response time, available resources, traffic picture, people evacuating to the north of the tunnel, reduced mobility amongst road users and limited communication means. Even though the questions did not permit detailed elaborations and informants differed in their articulations, these responses provided insights into how informants assessed those situations and how the listed uncertainties were appraised. How they would address the uncertainties differed from giving standardized responses to adaptive future-oriented strategies.

It was found that most informants demonstrated a proactive approach in addressing concerns about specific factors. These concerns were most frequently associated with: i) the nature of the fire, ii) the unknown goods of the vehicle, and iii) road users potentially trapped in smoke. A central tendency was manifested through activities aimed at obtaining additional information to construct a better understanding of the situation and establish a context-specific response. The informants engaged in what might be referred to as 'precautionary planning' prior to initiating extinguishing the fire or the rescue operation, addressing a prominent concern regarding the risks that might affect their personal safety. Overall, the information requested for the preliminary planning sought to clarify whether it was deemed safe to advance towards the fire scene and start the response operation, the number and location of road users in the tunnel and the predefined ventilation direction. We noted that both operational commanders and firefighters regarded the information provided in the initial phase as insufficient to make informed decisions.

The analysis indicates differences in the concerns expressed by the informants and their actions. It appears that this discrepancy relates to contrasting interpretations of critical factors to be assessed and the associated risks and uncertainties. A key finding reveals that some informants were narrowly focused on assessments of risks and uncertainties affecting the firefighting conditions and to a lesser extent on conditions affecting road users' health and safety. Only a minority focused on concerns about road users with reduced mobility and limited communication means, who might potentially become exposed to smoke. Moreover, the issue of response time (17 min) in the second scenario was rarely mentioned or considered. Yet, time factors play an important role in tunnel fire responses and the subsequent decisions and actions [16]. Regardless, neither operational commanders nor firefighters explicitly addressed this issue when they expressed concerns or prioritized response actions. Some informants sought to understand the situation based on comprehensive situational assessments prior to

planning the response. For instance, these informants reported specific concerns about the prolonged response time, the unknown fire substances, road users' behaviour in crises and their opportunity to evacuate to safe shelters. The traffic scenarios were considered in terms of vehicles inhibiting the incident location; insufficient extinguishing capacity and enough air to operate safely were also emphasized as critical factors.

4.4.2. Information gathering

Information gathering comprises statements concerning the search for updated information to formulate a risk assessment[1] of the environment and to clarify potential hazards and evaluate possible response strategies. During the alarm and en route phases, we expected to find preparations in the form of requesting and gathering additional information as the main priorities. Statements such as "seek updated information related to the nature and location of the fire", "seek updated information related to the number of road users potentially trapped in smoke" and "request the Road Traffic Centre" (RTC) and 110 emergency central to convey camera information" form the basis of this concept.

It is well established amongst firefighters that information gathering is prioritized in the en route phase [35]. However, this might not be informants actively seeking information, but information directed to preparations in the vehicles. Most informants showed a tendency to view victim treatment as outside their roles. Those informants highlighting information gathering during the entire scenarios were seemingly more autonomous than those restricting information gathering to the earliest phase. The latter informants expected involvement in operations but relied on instructions from leaders. There were also differences in the informants' expectations about information from the RTC and the need for knowledge about potential or actual victims downstream of the fires. The analysis indicated that only a minority of informants recognized this information as critical for the response operation. Apparently, the informants prioritized receiving confirmation of the predefined ventilation direction or discussing potential hazards with the crew members, which is consistent with what was privileged when addressing concerns and uncertainties.

Operational commanders at scene carry a much heavier load related to information gathering and developing tactics and strategies for the fire and rescue operations. Generally, the informants from this group are more reflective than firefighters. Full-time leaders are found to be more inquiring than part-time leaders. However, very few informants raised concerns about uncertainties and engaged in proactive judgements to assess the situations. Also, as above, amongst the operational commanders, there was a tendency to de-emphasize patient treatment as their major task and responsibility.

4.4.3. Common situational awareness

Statements about common situational awareness relate to the information secured and shared by the informants and what should be discussed and appraised within the firefighting crew. This appraisal is essential to assess the level and scale of the incident and, subsequently, determine adequate response tactics. It was anticipated that the informants would engage in choices of action related to creating common situational awareness. This included the items: "discuss/recognize with the team potential hazards of the operation", "ensure that the team has a common understanding of the situation" and "inform the crew/first responder teams".

Informants' responses were found to be consistent with the taught practices of the fire department. A common feature that we observed, especially in the second scenario, was that some informants ensured that the updated information would be discussed and correctly understood within the entire team. Achieving common situational awareness in emergency responses is a difficult task. Generally, the group's attitudes to prioritizing this task in accordance with the taught practice can be regarded as a positive effort to reduce uncertainties and obtain a valid comprehension of the situation.

4.4.4. Lifesaving activities – patient treatment

Ensuring the road users' safety constitute the core aim of emergency response activities. These lifesaving activities prompted the following statements: "ensure that no victims with need for first aid are left outside tunnel" and "start first aid/Cardiopulmonary resuscitation (CPR) for victims in close vicinity". When confronted with choices regarding either executing response operations or providing medical assistance, most informants selected to engage in actions related to firefighting. It seems that some informants believe medical treatments are others' responsibilities. At the incident scene, however, some informants prioritized medical assistance for victims before engaging in combating the fire.

There were diverse priorities and emphases amongst the informants. In the initiating phase, however, a relatively high number of firefighters and operational commanders chose to investigate the type and severity of the incident by continuously searching for updated information or ensuring common situational understanding, which shows responsibility in lifesaving activities. Hence, the decision-making process was active and engaged, but priorities were arrayed inconsistently across the informants.

4.4.5. Facilitating self-rescue

In Norway, facilitating self-rescue is a key premise for emergency management in tunnel fires. Safety becomes a matter of ensuring optimal conditions for safe self-evacuation and eliminating the critical factors which may affect road users' health and safety. Self-recue is conceptualized through the items: "ensure that head on traffic is evacuated and vehicles parked and controlled" and "request the RTC to broadcast radio instructions". It was anticipated that the informants would prioritize road users' awareness and facilitate the evacuation process. Road users downstream of the fire are likely to be exposed to very harmful toxic fumes. Yet, despite the concerns addressed regarding road users potentially exposed to hazards, only a minority of informants prioritized instructing the RTC to broadcast radio messages or to inform road users to evacuate, while they prepared to enter the fire scene. A clear priority was to extinguish the fire as soon as possible. The purpose was to provide access for the search and rescue teams to rescue people potentially trapped in smoke.

As noted earlier, the analysis revealed considerable variations amongst the informants. A minority of the operational commanders emphasized broadcast radio instructions to guide the evacuation process. Contrary to taught practices, in the second scenario, many informants considered initiatives to establish contact with additional resources as central to ensuring adequate response. We assume that these informants expected a lengthy response operation and addressed the need for additional resources as the key issue.

4.4.6. Firefighters' safety

A fundamental responsibility of operational commanders is to ensure the safety of the firefighting crew under their command. All crew members must have a clear understanding of how decisions may affect their safety, encompassing the items: "ensure own safety" and "critically assess all conditions that might threaten the safety of first responders".

The data indicates that firefighters and operational commanders put personal safety first, which appears to be both an internalized and culturally conditioned norm. The informants prioritized thorough evaluations of the situation and attempted to identify conditions that may cause harm or injury before considering advancing towards the incident scene and starting the response operation. We have not identified any critical deviations concerning first responders' assessments of personal safety.

[1] A reflexive evaluation based on the most updated and available information.

4.4.7. Clarifying response actions

A primary task of the operational commander leading the response operation is to determine the goals of the tactical plan and clearly communicate them to the firefighting crew. Communication requires accuracy. It is essential that the contents of the information exchanged are understood by the entire response team. Clarifying response actions are related to: "discussing/identifying with team members possible response tactics", "ensuring that the operation is understood", "expecting clear goals with the tactical plan for the response from leader" and "communicating the goals and plan for the response tactics to first responders".

This data indicates that informants prioritized these actions in accordance with the taught procedures. Some informants were observed as being especially focused on seeking clarification of response actions and communicating the plan for the response as their main priority. As a result, requesting information about road users downstream of the fire or ensuring that no victims needing first aid were left outside the tunnel received less priority.

4.4.8. Confirming procedures

When responding to large-scale tunnel fires, the most experienced firefighter first arriving at the scene acts as incident commander. This role comprises taking overall responsibility for the effective and safe execution of the operation. With the arrival of other personnel, the incident commanding roles will change to those in charge either within the tunnel or the incident commander outside coordinating the operation. Confirming procedures relate to statements such as: "confirmation from leader that ventilation is in predefined direction", "confirmation that RTC has launched radio instructions", "confirmation from leader what steps RTC has taken and "confirmation from RTC and 110 emergency central that ventilation is in predefined direction and clearing the site".

Typically, the informants expected a lengthy operation and wanted to establish contact with fire extinguishing and rescuing resources at the north side of the tunnel. Another tendency from the incident commanders' reported approach was that some of them prioritized establishing contact with other emergency response units rather than attempting to receive confirmation from the RTC and 110 emergency central that the ventilation was running in the predefined direction.

It was expected that choices of action were directed towards ensuring conditions for effective firefighting and assisting road users to evacuate the tunnel. It is questionable, however, whether this was the prevailing practice within the fire department. An important finding was that only a minority of the firefighters possessed understanding about how information conveyed by the RTC might provide effective support to road users. Many informants requested confirmation of procedures to ensure correct fire ventilation and advance towards the fire scene.

4.4.9. Fire and rescue resources

Major tunnel fires involve many emergency services and agencies providing information and assistance with resources. First responders involved in tactical and operational decisions need to prioritize conducting assessments of resources to plan and prepare for a complex operation. However, in accordance with the taught practices, assessments of resources should be conducted after information has been gathered and procedures confirmed. Fire and rescue resources comprise the items: "ensure that additional resources are en route" and "confirmation of all resources that are en route to the incident site".

The data shows that the informants assessed the complexity of the situation, the limitations of equipment and the likely development when engaged in prioritizing choices of action and response strategies. Upon arrival at the incident scene, the majority assessed the available resources against the tactical goal and started arrangements to request additional support. It was found that firefighters' priorities regarding resources were consistent with the taught practices. The informants expressed concerns about the available resources and emphasized the need for more of them. Contrary to the taught practices, some operational commanders concentrated on establishing contact with other emergency response units prior to assessing resources.

4.4.10. Response tactics (firefighters)

A fundamental principle amongst first responders is "extinguish to rescue". The prevailing tunnel fire response strategy prioritizes immediately combating the fire over conducting search and rescue. The purpose is to ensure a safer working environment and ease the conditions for conducting the search and rescue. The concept of response tactics is assessed from two statements: "start to mount hoses and secure area" and "initiate extinguishing".

Informants reported engaging in tactical decision-making. The immediate priority was to halt the fire escalation and reduce threats for road users evacuating the tunnel. Although the taught practices, we noted contrasting understandings of sequences in choices of action. Some firefighters wanted to start search and rescue prior to extinguishing the fire. A clear tendency was informants' eagerness to start to extinguish the fire or to search for people, rather than gathering information about vehicles and people downstream in the tunnel. It was also observed that informants expressed concerns regarding unknown goods in the initiating phases but were less consistent during the emerging scenario. It was expected that they would prioritize information gathering to identify risk and hazards so that relevant control measures could be implemented, but this assumption was not clearly evident from their responses.

4.4.11. Communication and cooperation (operational commanders)

Finally, fire and rescue services must communicate and cooperate with each other and with other emergency response services (i.e., health, police, road operators, emergency centrals) to succeed with the response operation. We expected operational commanders to take initiatives. Communication and cooperation relate to the following items: "establish contact with fire and rescue team at the north side" and "window report/9-8 message in a common voice channel". The findings suggest that all but one informant answered in accordance with taught procedures. Some went too far in their prioritization and downsized ensuring common situational understanding or communicating the tactical plan to first responders.

5. Discussion

In this study, the Norwegian fire and rescue personnel characterize their tunnel knowledge in three dimensions: i) *Emergency response and tunnel system knowledge*, ii) *Practical tunnel condition knowledge* and iii) *Theoretical (physical and behavioural) knowledge*. The respondents assess the level of their *Theoretical (physical and behavioural)* and *Emergency response and tunnel systems* knowledge as high. These dimensions are related to general understanding and responsibilities associated with being an employee in the response units in the fire and rescue services. Further, their *Practical tunnel condition* knowledge was scarce, which was unanticipated and surprising, given the fact that tunnels represent complex and possibly dangerous challenges for the personnel themselves. An interpretation of these findings is that the respondents rely on and emphasize their general emergency response knowledge and deem it sufficient in any situation, regardless of which object they need to work on.

The analyses demonstrated that the first responders' self-evaluation of competence was significantly higher amongst full-time personnel and those in leading positions, than their part-time colleagues. It can be claimed that the structure of the Norwegian fire and rescue services puts them into "A and B – teams", consisting of full-time and part-time fire and rescue services, respectively. However, the detailed study shows no significant differences in first responder's competence based on their employment position and significant deviations for common situational awareness amongst leaders. From the analysis of actual competence,

only a minority of informants showed judgements that went beyond established procedures in choosing strategies to combat these situation-specific incidents. These informants tended to conduct more comprehensive assessments of risk prior to engaging in strategies and response tactics. However, proactive judgements incorporating creative problem-solving skills to uncover risks and uncertainties were seldom reported. Although we anticipated finding important concerns about scenario uncertainties and more comprehensive situational assessments amongst operational leaders, we did not identify judgements that clearly distinguished them from the firefighters. Very few informants raised concerns about the performance of engineered systems, such as communication systems, ventilation systems, passive fire protection or evacuation systems. Experiences from previous fires in Norwegian tunnels show shortcomings of various systems.

The two studies presented here provide insights into tunnel fire response competencies from different perspectives. As an overall judgement of first responders' self-reported competence, it seems to predict inaccurately the real competence required by the fire and rescue service responders. There is a gap in actual versus perceived competence, as the detailed study of actual competence is inconsistent with the national survey of perceived competence. Nor is it correct to say that our measured actual competence equals real competence. "Real competence" is a construct that is very difficult or even impossible to reveal. It could be considered a stable capability of a single person, a team or an entire fire department responding to tunnel fires. However, all tunnel fires are different, as are the response organizations (encompassing all emergency services). Very rarely are response operations publicly investigated, and the in-house assessments are informal, without any explicit methods. In Norway, amongst the tunnel fires presented in Table 1, only the first Gudvanga tunnel fire encompassed an assessment of the responders, because obvious flaws were observed [4]. An interesting perspective to reveal the decisions and actions of real responses is using helmet cameras and designing follow-up assessments [36], but this will also be context-dependent and must not be addressed as "real competence".

The methods used in this study differed in that the local study counted and assessed deviations from taught priorities. We think the study is an important step to elaborating the performance of emergency response units as part of the overall tunnel fire safety management. Further triangulations could be designed by also assessing data from real events, exercises and training activities. This is ongoing work designed as courses (Erasmus + - SAFEINTUNNELS – [37], which are now in operation and included as an action research study. However, our findings indicate the need to enhance critical discussions about fire safety performance, for example included in mandatory risk analyses. An important part of the local study was to generate data on uncertainties and challenges with remote, but possible, demanding fire scenarios in tunnels: How should such events be understood in the current response practices? The informants were all experienced firefighters/leaders, and not one questioned the philosophy of extinguishing before rescue. It seems that the informants have limited concerns regarding both how ventilation systems can assist self-rescue, and uncertainties that should be considered when activating the ventilation strategy. Smoke control is an unresolved issue.

There are some limitations and strengths in the present study that should be considered when interpreting the findings. The sample frame for the national study was all fire and rescue personnel with tunnels longer than 1 km in their area. Although we have achieved a relatively high response rate, the target group was approached through the fire and rescue chiefs. Thus, the ultimate decision of who should receive the questionnaire and participate in the study was left to them. A common difficulty when using questionnaires as a research tool is that the identified questions may be interpreted differently by the respondents than the researcher intended [38]. Another implication is that the data produced will lack details or depth on the topic being investigated [39]. The pretesting procedure helped us ensure the validity of the coverage of questions and minimize the risk for potentially misleading results, before distribution. Furthermore, the qualitative investigation and the panel used to interpret the results have provided in-depth and nuanced information on the current tunnel fire response practices within the fire department. While this study is conducted in the Norwegian context, there may be lessons to also be learned for other countries that have tunnels as part of their road infrastructure. Since the Norwegian road infrastructure consists of more than 1200 tunnels, it is reasonable to assume that the fire and rescue services are at least as well equipped with tunnel fire response competencies as other countries with a smaller number of tunnels. We also acknowledge the huge variation of safety standards seen in Norwegian tunnels, which is a challenge for the fire and rescue services.

Tunnel fire response operations are aimed at saving human lives and preventing or reducing physical or mental harm to road users. Usually, this is executed through direct efforts at the incident site or through targeted assistance at the operational level. The current firefighting strategy, however, poses the dilemma between the safety of road users and that of first responders. What risks should the emergency personnel take to save lives? A deep-rooted principle amongst first responders is: "you shall not risk a life to save a life!" [40]. This principle informs the fire and rescue services' response behaviour and must be taken into account in the design of fire ventilation strategies, road-user communication in emergencies and fire safety management in general.

6. Conclusion

The main objective of this study was to examine how employees in the Norwegian fire department regard their own competence and the extent to which these self-evaluations of competence reflect the actual level of competence within the Norwegian fire department. Self-evaluated competence varies with position in the fire department and whether or not the fire department is a part-time or full-time service. These findings were expected. However, the competence was connected with general emergency response premises and not the local specific knowledge about the tunnels in the respondent's area of responsibility. Furthermore, the study of actual competence revealed another picture, in which the differences between positions were blurred and more individually based. In all, we need to challenge competencies in tunnel fire safety from different angles to provide an enhanced understanding of how to work with tunnel fire safety management in the future.

In summary, this study is an important step towards understanding the capability of fire and rescue services to tackle major tunnel fires. The findings show discrepancies in first responders' tunnel fire response competence at the operational and tactical levels and provide insight into the content of these discrepancies. To enhance performance during tunnel fire responses, educational programmes should facilitate contents that specifically address challenges and uncertainties that operational leaders and firefighters encounter in tunnel fires. A tendency seen in the studies is the dilemma of providing self-rescue conditions for the exposed road users and the safety of firefighters entering the tunnel to the fire incident. Furthermore, the study addresses the need to educate first responders in the special features of local tunnels, safety issues during emergency operations in tunnels, ventilation systems, human behaviour in crises and principles for emergency response management.

Author statement

Gabriela Bjørnsen: methodology, formal analysis, investigation, writing original draft.

Stephen Billett: conceptualization, writing – review and editing.

Ove Njå: writing – review and editing, supervision, formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial

interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.firesaf.2023.103758.

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Article V

Towards an understanding of learning within the Norwegian fire and rescue services – Focusing on tunnel fire safety

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Article VI

Vocational learning of incident commanders in tunnel fire safety work

Authors: Bjørnsen, G., & Njå, O.

Published in: *Australian Journal of Adult Learning: Contributions of workplace experiences to adults' lifelong learning*

Appendices

Appendix A – National questionnaire for fire and rescue services

Kjære medarbeider,

Denne undersøkelsen handler om din rolle i brann- og redningstjenesten og i hvilken grad du er forberedt på å ivareta sikkerheten i norske vegtunneler. Brann- og redningstjenesten har roller knyttet til: forebyggende arbeid, hvor tilsyn og saksbehandling er relevante aktiviteter, alarmsentralen, hvor kommunikasjon og koordinering er relevante oppgaver, beredskapsarbeid, knyttet til innsats og ulykkeshendelser i tunneler. Ulykker og branner i vegtunneler kan være noen av de mest komplekse og krevende innsatsene brann- og redningstjenesten blir involvert i.

Vi ønsker å kartlegge hvordan opplæringsaktivitetene bidrar til utviklingen av kunnskap og kompetanse i tunnelbrannsikkerhet. Det er derfor viktig at du svarer på spørsmålene oppriktig og etter beste evne, uten bruk av oppslagsverktøy eller hjelp fra andre.

Når du får spørsmål knyttet til tunneler i ditt ansvarsområde, sikter vi til tunnelene du med stor sannsynlighet vil bli involvert i. Undersøkelsen er frivillig og tar ca. 20 minutter å besvare.

Kjønn

(1) ❑ Mann
(2) ❑ Kvinne

Alder

(1) ❑ Under 30 år
(2) ❑ 30-39 år
(3) ❑ 40-49 år
(4) ❑ 50-59 år
(5) ❑ 60 år eller mer

Fylket hvor brannvesenet ditt er lokalisert

(1) ❑ Østfold
(2) ❑ Akershus

(3) ❑ Oslo
(4) ❑ Hedmark
(5) ❑ Oppland
(6) ❑ Buskerud
(7) ❑ Vestfold
(8) ❑ Telemark
(9) ❑ Aust-Agder
(10) ❑ Vest-Agder
(11) ❑ Rogaland
(12) ❑ Hordaland
(13) ❑ Sogn og Fjordane
(14) ❑ Møre og Romsdal
(15) ❑ Trøndelag
(16) ❑ Nordland
(17) ❑ Troms
(18) ❑ Finnmark

Din høyeste utdanning

(1) ❑ Grunnskole
(2) ❑ Videregående skole
(3) ❑ Teknisk fagskole
(4) ❑ Universitets- og høgskole (1-3 år)
(5) ❑ Universitets- og høgskole (mer enn 3 år)
(6) ❑ Annet _____

Hvilken stilling har du i brannvesenet?

(1) ❑ Brann- og redningssjef
(2) ❑ Leder beredskap
(3) ❑ Seksjonsleder beredskap
(4) ❑ Leder forebyggende

(10) ❑ Seksjonsleder forebyggende
(5) ❑ Leder nødsentral
(6) ❑ Brigadesjef
(11) ❑ Utrykningsleder/ Brannmester
(7) ❑ Brannkonstabel
(8) ❑ Branninspektør
(9) ❑ Nødsentral vaktleder
(12) ❑ Nødsentral operatør
(13) ❑ Annet _____

Stillingsomfang

(1) ❑ Fulltid
(2) ❑ Deltid
(3) ❑ Annet _____

Erfaring - antall år i brannvesen

(1) ❑ Mindre enn 1 år
(2) ❑ 1-5 år
(3) ❑ 6-10 år
(4) ❑ 11-15 år
(5) ❑ 16-20 år
(6) ❑ 21-25 år
(7) ❑ 26-30 år
(8) ❑ Mer enn 30 år

Hvilken vaktordning er du ansatt i?

(1) ❑ Kasernert døgn
(2) ❑ Kasernert dagtid
(3) ❑ Deltid med vakt
(4) ❑ Deltid uten vakt
(5) ❑ Depot

(6) ❑ Annet _____

Brannvesenets organisering og samarbeid:

(1) ❑ Interkommunalt selskap (IKS)
(2) ❑ Etat i kommunen
(3) ❑ Samarbeid med andre kommuner
(4) ❑ Samarbeid med Forsvaret
(5) ❑ Samarbeid med industrivernet
(6) ❑ Annen form for organisering _____

Din formelle brannfaglige opplæring (Sett gjerne flere kryss)

(1) ❑ Intern opplæring i eget brannvesen
(2) ❑ Nettbasert kurs i brannvern
(3) ❑ Grunnkurs heltid
(4) ❑ Grunnkurs deltid
(5) ❑ Beredskapsutdanning trinn I heltid
(6) ❑ Beredskapsutdanning trinn I deltid
(7) ❑ Beredskapsutdanning trinn II
(8) ❑ Beredskapsutdanning trinn III
(9) ❑ Utrykningslederkurs del A og B
(10) ❑ Utrykningslederkurs del C
(15) ❑ Kurs for alarmesentraloperatør
(12) ❑ Yrkesutdanning i forebyggende brannvern
(13) ❑ Annen brannteknisk utdanning
(14) ❑ Annet (beskriv) _____

Hvor mange tunneler, lengre enn 1 km, finnes det i området du vanligvis er lokalisert i?

(1) ❑ 1-5
(2) ❑ 6-10
(3) ❑ 11-20

(4) ❑ 20 +

(5) ❑ Vet ikke

Hva slags tunneler finnes det i ditt ansvarsområde? (NB! Svar etter beste evne, uten bruk av hjelpemidler).

Med ansvarsområde mener vi de tunnelene du med stor sannsynlighet kommer til å gjøre en jobb med, enten før uønskede hendelser har inntruffet eller som respons på uønskede hendelser.

Beskriv de tunnelene som du oppfatter som mest kritiske med hensyn til tunnelsikkerhet, f.eks. de som er lengst, har størst trafikkmengde, dårligst sikkerhetsutrustning, dårlig vedlikehold, med mer. Du kan beskrive maksimalt 5 tunneler.

Tunnelnavn

_____

Type krysning

(1) ❑ Undersjøisk

(2) ❑ Landbasert

Antall løp

(1) ❑ Ettløpstunnel

(2) ❑ Toløpstunnel

Lengde

(1) ❑ Antall meter _____
(2) ❑ Vet ikke

Stigning

(1) ❑ Mer enn 5%
(3) ❑ Mindre enn 5%
(2) ❑ Vet ikke

Sikkerhetsutrustning

(1) ❑ Liten (f.eks. slokkevann og nødstasjoner)
(2) ❑ Middels (f.eks. havarinisjer, nødstasjoner, slokkevann, ventilasjon, ITV-overvåkning, nødnett)
(3) ❑ Stor (f.eks. ventilasjon, rømningslys, ITV-overvåkning, nødnett, høyttalersystem, fjernstyrte bommer, slokkevann, havarinisjer, nødutganger/ tverrforbindelser)
(4) ❑ Vet ikke

Årsdøgntrafikk (gjennomsnittlig antall kjøretøy gjennom tunnelen i døgnet)

(1) ❑ Antall _____
(2) ❑ Vet ikke

Andel tunge kjøretøy av Årsdøgntrafikk

(1) ❑ % _____
(2) ❑ Vet ikke

Opplæring og erfaring med tunnelsikkerhet

Vi ønsker at du skal tenke tunnelsikkerhet i resten av undersøkelsen.

Tunnelsikkerhet handler om alle tiltak som skal hindre at tunnelbrann og andre uønskede hendelser inntreffer, eller tiltak som skal redusere konsekvensene av hendelser.

Din formelle opplæring i tunnelsikkerhet (Sett gjerne flere kryss)

(1) ❑ Innsats i tunneler - 2 timer grunnkurs ved NBSK
(2) ❑ Tunnelseminar i Runehamar testtunnel
(3) ❑ Intern opplæring i eget brannvesen
(4) ❑ Annen opplæring i tunnelsikkerhet i regi av andre aktører (beskriv) _____
(5) ❑ Ingen

Har du gjennomført opplæring i forebyggende sikkerhetsarbeid i tunneler?

(1) ❑ Ja
(2) ❑ Nei
(3) ❑ Vet ikke

Hvor mange kurs eller opplæringsaktiviteter i forebyggende sikkerhetsarbeid har du deltatt på?

(1) ❑ 1-5
(2) ❑ 6-10
(3) ❑ 11-20
(4) ❑ 20 +
(5) ❑ Vet ikke

Opplæringsaktivitetene har vært i regi av: (Sett gjerne flere kryss)

(1) ❑ Norges brannskole
(2) ❑ Statens vegvesen (region, distrikt)
(3) ❑ Statens vegvesen - Vegtrafikk sentralen
(4) ❑ Andre aktører (beskriv) ____

Erfaring med forebyggende sikkerhetsarbeid i tunneler

Har du vært involvert i aktiviteter knyttet til tunnelplanlegging, og/eller -bygging?

(1) ❑ Ja
(2) ❑ Nei
(3) ❑ Vet ikke

Har du vært involvert i aktiviteter knyttet til drift og/eller vedlikehold av tunneler?

(1) ❑ Ja
(2) ❑ Nei
(3) ❑ Vet ikke

Har du vært involvert i aktiviteter knyttet til risikoanalyse og/eller beredskapsanalyse av tunneler?

(1) ❑ Ja
(2) ❑ Nei
(3) ❑ Vet ikke

Erfaring med uønskede hendelser i tunneler

Har du vært involvert i redningsaksjoner knyttet til trafikkulykke i tunnel?

(1) ❑ Ja
(2) ❑ Nei

Har du vært involvert i rednings- og slokkeaksjoner knyttet til brann i tunnel?

(1) ❑ Ja
(2) ❑ Nei

Har du vært involvert i hendelse med farlig gods i tunnel?

(1) ❑ Ja

(2) ❑ Nei

Hvor mange innsatser eller aksjoner i tunneler har du vært involvert i?

(1) ❑ 1-5

(2) ❑ 6-10

(3) ❑ 11-20

(4) ❑ 20 +

(5) ❑ Vet ikke

Hva slags type innsatser eller aksjoner var det? (Sett gjerne flere kryss)

(1) ❑ Bergingsaksjon

(2) ❑ Trafikkulykke

(3) ❑ Brann i personbil

(4) ❑ Brann i tyngre kjøretøy

(5) ❑ Utslipp av farlig gods/ brennbart materiale

(7) ❑ Varmgang i bremser/ motor

(6) ❑ Annet _____

Hvilken rolle har du hatt i forbindelse med uønskede hendelser i tunneler? (Markèr for den rollen du har hatt flest ganger eller den du mener var viktigst)

(1) ❑ Overbefal/ Aksjonsleder brann

(9) ❑ Innsatsleder brann

(8) ❑ Utrykningsleder

(2) ❑ Røykdykkerleder

(3) ❑ Røykdykker /Brannkonstabel

(4) ❑ Alarmsentral

(5) ❑ Ledelse fra brannstasjon - stab

(7) ❑ Sjåfør

(6) ❑ Annet _____

Hvordan vil du beskrive alvorlighetsgraden av den mest kritiske hendelsen du har vært involvert i?

(1) ❑ Svært alvorlig (Omkomne og/ eller alvorlig personskade og/ eller tap av store materielle verdier)
(2) ❑ Alvorlig (Alvorlig personskade og/ eller tap av materielle verdier)
(3) ❑ Moderat (Mindre personskade og/ eller mindre tap av materielle verdier)
(4) ❑ Mindre alvorlig (Ingen person skade og ubetydelige tap av materielle verdier)

Hvordan vil du beskrive vanskelighetsgraden av den mest kritiske hendelsen du har vært involvert i?

(1) ❑ Svært kompleks slokke- og redningsaksjon
(2) ❑ Kompleks slokke- og redningsaksjon
(3) ❑ Kompleks slokkeaksjon
(4) ❑ Kompleks redningsaksjon
(5) ❑ Enkel slokke- og redningsaksjon
(6) ❑ Enkel redningsaksjon
(7) ❑ Enkel slokkeaksjon

Nærmere om øvelser og opplæringsaktiviteter i eget brannvesen

I denne delen ser vi på alle øvelser og opplæringsaktiviteter knyttet til innsats og respons i tunneler. Vi avgrenser til aktiviteter som skjer i eget brannvesen, men ikke inne i tunneler i drift.

Vi skiller på type øvelser og opplæringsaktiviteter. Det kan være klasseromsundervisning, trening og testing av utstyr hos leverandører, trening og øvelser på brannstasjonen, eller trening og øvelser på øvingsfelt. Vi tar også med samtrening og øvelser med

nabobrannvesen og de andre nødetatene. Vi tenker kun på øvelser og opplæring knyttet til tunnelsikkerhet.

Hvor ofte har du deltatt i øvelser og opplæringsaktiviteter knyttet til tunnelhendelser?

(1) ❑ Månedlig
(2) ❑ Årlig
(3) ❑ Sjeldnere enn en gang i året
(4) ❑ Aldri

I hvilken grad opplevde du at øvelsene og opplæringsaktivitetene dekket:

Brann og røykutvikling i tunneler med spesielle særtrekk (med særtrekk menes for eksempel lange, bratte, undersjøiske ettløpstunneler)	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Beslutningstaking og ansvarsfordeling ved brann i tunnel	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Kommunikasjonsutfordringer ved brann i tunnel	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Menneskelig atferd i tunnelbrann	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Evakuering av mange mennesker innhyllet i røyk over lengre avstander	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Giftighet av røykgasser	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

Slokkemetoder	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Risiko ved slokking av brann i tunnel (for eksempel fare for ras)	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Søkemetoder	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Håndtering av usikkerhet (f.eks. usikkerhet om brannmedium, eksponerte mennesker, tidsaspekter, egne slokkestrategier, med mer)	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Ventilasjonsstyring- og retning	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

Hvor mange ganger har du deltatt i samvirkeøvelser?

(1) ❑ Ingen
(2) ❑ Antall _____

I etterkant av samvirkeøvelsen/ -ene, gikk dere gjennom identifiserte læringspunkter?

(1) ❑ Ja
(2) ❑ Nei
(3) ❑ Vet ikke

Ble læringspunktene inkludert i nye opplæringsaktiviteter?

(1) ❑ Ja
(2) ❑ Nei
(3) ❑ Vet ikke

Hvilke endringer medførte læringspunktene?

(1) ❑ Endring i prosedyrer/ rutiner
(4) ❑ Nyanskaffelse av utstyr
(5) ❑ Annet _____
(6) ❑ Vet ikke

I hvilken grad opplevde du samvirkeøvelsen/-ene til å ha overføringsverdi til reelle hendelser i tunnel?

(1) ❑ Svært liten grad
(2) ❑ Liten grad
(7) ❑ Noen grad
(4) ❑ Høy grad
(5) ❑ Svært høy grad
(6) ❑ Vet ikke

Læring

I denne delen ønsker vi å få innsikt i hvordan du opplever opplæringen i tunnelsikkerhet. Vi er opptatt av hva du mener er viktig for deg når du lærer, og hvordan det blir tilrettelagt for det.

I hvilken grad har du opplevd opplæringsaktivitetene som:

Motiverende for mine arbeidsoppgaver med innsats/ beredskap og/ eller andre	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

oppgaver angående sikkerhet i tunneler					
Relevante for mine arbeidsoppgaver med innsats/ beredskap og/ eller andre oppgaver angående sikkerhet i tunneler	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Stimulerende til nytenkning omkring mine arbeidsoppgaver med innsats/ beredskap og/ eller andre oppgaver angående sikkerhet i tunneler	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
I hvilken grad har du opplevd at:					
Instruktørene har vært kompetente i forhold til tema/ -ene det ble undervist i	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Instruktørene har gitt konkrete tilbakemeldinger/vurderinger på min utvikling og mitt læringsutbytte	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Opplæringsmateriellet har vært relevant for mine arbeidsoppgaver	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Det var god balanse mellom teori og praksis	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
I hvilken grad har du hatt læringsutbytte av:					

Seminar/ workshop (gjennomgang av ulike scenarier)	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(6) ❑
Bordøvelse/ tabletop (diskusjonsbaserte aktiviteter hvor deltakerne er samlet i et rom)	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(6) ❑
Spilløvelse (deltakerne fyller roller som ligger så nært opp til sitt ansvar og yrkesroller som mulig)	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(6) ❑
Ferdighetstrening (aktiviteter avgrenset til trening på konkrete ferdigheter)	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(6) ❑
Funksjonsøvelse (aktiviteter hvor det prøves ut enkelte funksjoner som er identifisert som viktige for å mestre reelle hendelser)	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(6) ❑
Fullskalaøvelse (aktiviteter som involverer flere etater for å løse større og mer komplekse oppgaver)	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑	(6) ❑

I hvilken grad ble det brukt tid på å diskutere innholdet i opplæringsaktivitetene? (f.eks. før, underveis eller i etterkant av en opplæringsaktivitet)

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

I hvilken grad opplevde du at diskusjoner på samlinger medførte refleksjon?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

I hvilken grad har du opplevd at opplæringsaktivitetene:

Har medført endringer i hvordan jeg utfører mine arbeidsoppgaver knyttet til tunnelsikkerhet	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Har bekreftet mine kunnskaper, ferdigheter og måten jeg jobber med tunnelsikkerhet	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Har gitt meg en dypere forståelse av viktige forhold knyttet til mine arbeidsoppgaver i tunnelsikkerhet	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

Erfaringslæring

I denne delen ønsker vi å få innsikt i hvordan det jobbes med konkrete hendelser fra vegtunneler som du eller andre i ditt brannvesen har vært involvert i. Det kan også være hendelser som er gransket av andre.

I hvilken grad opplever du å bli involvert i:

Uformelle samtaler i etterkant av uønskede hendelser i tunneler	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Oppfølgingsmøter i etterkant av uønskede hendelser i tunneler	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

I hvilken grad opplever du at:

Det blir utarbeidet konkrete læringspunkter i etterkant av uønskede hendelser i tunneler	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Læringspunktene blir fulgt opp i organisasjonen	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

I hvilken grad opplever du at evalueringsrapporter (f.eks. interne rapporter, eksterne rapporter, etc.) i etterkant av uønskede hendelser i tunneler er nyttig for:

Din læring	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Andre som ikke har vært med på hendelsen	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

I hvilken grad opplever du at erfaringer fra hendelser i tunneler utenfor eget brannvesen trekkes inn i egen organisasjon?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

Kjennskap til tunnelene i ditt brannvesens ansvarsområde

I denne delen ønsker vi at du selv vurderer din kunnskap og kompetanse innen tunnelsikkerhet i de tunnelene du kan bli involvert i.

Hvor godt kjenner du til tunnelens/ tunnelenes:

Særegenheter og utforming	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Sikkerhetsutrustning og ressurstilgang (vannforsyning i tunnelen, rømmningsmulighter, ventilasjon, videoovervåkning, samband dekning, osv.)	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Beredskapsplaner og objektplaner (angrepsveier, rømmningsmulighter, ventilasjonsretning, osv.)	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Prosedyrer og tiltakskort for uønskede hendelser	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Tilstand (teknisk og driftsmessig)	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

Status fra tilsyn med tunnelene	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

I hvilken grad har du kjennskap til tilgjengelige ressurser (f.eks. mannskaper, slokkeutstyr, røykdykkeutstyr, kjøretøy, osv.) i eget brannvesen ved en stor tunnelbrann?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

I hvilken grad har du kjennskap til tilgjengelige ressurser (f.eks. mannskaper, slokkeutstyr, røykdykkeutstyr, kjøretøy, osv.) i nabobrannvesen ved en stor tunnelbrann?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

I hvilken grad kjenner du til hvordan tunnelen/ tunnelenes:

Sikkerhetsnivå blir opprettholdt	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑
Sikkerhetsutstyr blir vedlikeholdt	(1) ❑	(2) ❑	(3) ❑	(4) ❑	(5) ❑

I hvilken grad kjenner du til hvordan trafikanter oppfører seg ved en stor tunnelbrann?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

I hvilken grad kjenner du til brannutviklingen ved store tunnelbranner?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

Tenk deg at du blir kalt ut til innsats på grunn av en stor tunnelbrann. Vurder din egen kompetanse til å kunne håndtere en slik situasjon.

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑ (6) ❑

Samvirke med myndigheter, tunneleier, Vegtrafikksentralen og andre nødetater når det gjelder tunnelsikkerhet

I denne delen vil vi ha din vurdering av samarbeidet mellom dere og andre viktige aktører i tunnelsikkerhetsarbeidet.

Hvordan vil du vurdere samarbeidet med tunneleierne i ditt distrikt? (Statens vegvesen, fylkeskommunen)

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

Hvordan vil du vurdere samarbeidet med Vegtrafikksentralen i ditt distrikt?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

Hvordan vil du vurdere samarbeidet med andre nødetater med tanke på ressurser og samhandling?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

Hvordan vil du vurdere samarbeidet med Direktoratet for samfunnssikkerhet og beredskap?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

Din vurdering av brannvesenets samlede kompetanse i tunnelsikkerhet:

I hvilken grad er ditt brannvesen kompetent til å håndtere utfordringene i tunnelsikkerhetsarbeidet?

(2) ❑ Liten kompetanse
(3) ❑ Noe kompetanse
(4) ❑ Tilfredsstillende kompetanse
(5) ❑ "Profesjonell"
(6) ❑ Ekspert

(7) ❑ Vet ikke

Takk for at du tok deg tid til å svare på våre spørsmål.
Trykk "Avslutt" for å sende inn ditt svar.

Appendix B – Actual competence investigation for firefighters

Du er stasjonert på Kvernevik brannstasjon og har førsteinnsats i begge scenariene beskrevet nedover. Din rolle er røykdykker. Besvarelsen skal ta utgangspunkt i tilgjengelige ressurser fra Kvernevik brannstasjon.

Scenario 1

Hendelse rapportert inn fra VTS til 110 sentralen - mandag 03. februar 2020, kl. 07.15.

- Varsel om røykutvikling og flammer i stor varebil. Kjøretøyet har stoppet i en havarinisje i bunnen av Byfjordtunnelen, i retning sør mot Randaberg.
- Kl. 07.16. VTS observerer at bilføreren trekker ut et brannslukningsapparat og forsøker å slukke brannen.
- 110 sentralen trippelvarsler og VTS stenger tunnelen i henhold til prosedyre for brann i kjøretøy.
- Brannventilasjon starter i henhold til prosedyre.
- Innringer melder at kjøretøyet tilhører Riska Sveis AS.
- Grunnet kraftig røykutvikling og brann, kl. 07.18. danner det seg kø bak kjøretøyet som brenner, i retning sør.
- Kl. 07.19. VTS melder å ha mistet bildet fra flere av kameraene nedstrøms for kjøretøyet, og at det blir mindre sikt på resterende kamera i retning nord.
- På dette tidspunktet befinner flere kjøretøy seg på vei ned mot brannen fra begge sider.
- Kl. 07.20. VTS melder at det observeres 4 vogntog ca. 200 meter sør for brannen. Disse har stilt seg i vegkanten av sitt kjørefelt med varsellys på.
- VTS melder også at det observeres 3 personbiler mellom disse vogntogene.

Åpent spørsmål (skriv tydelig, gjerne med blokkbokstaver):

Du har fått denne informasjonen og er nå på vei mot brannstedet. Hva er dine hovedbekymringer? Beskriv tre aktiviteter som bør ha høyest prioritet i denne fasen for å håndtere hendelsen.

Bekymringer knyttet til hendelsen:

3 aktiviteter knyttet til håndtering av hendelsen:

Med bakgrunn i denne informasjonen, hva er dine prioriteringer i de ulike fasene presentert nedenfor? Ranger fem av svaralternativene, hvor 1 betyr høyest prioritet og 5 lavest.

Du befinner deg i mannskapsbilen, på vei mot hendelsen. Det tar ca. 7 minutter å ankomme brannstedet. Hva er dine prioriteringer i denne første fasen?

- Jeg søker informasjon fra min nærmeste leder om hva som brenner, hvor det brenner og hvor mange trafikanter som befinner seg i tunnelen [ ]
- Jeg avstemmer med mine kollegaer potensielle farer ved innsatsen [ ]
- Jeg avstemmer med mine kollegaer potensielle farer for trafikanter som befinner seg inne i tunnelen [ ]
- Jeg avstemmer med mine kollegaer mulig innsatstaktikk [ ]
- Jeg får bekreftet fra min nærmeste leder at ventilasjonen går i forhåndsdefinert retning [ ]
- Jeg søker informasjon om hvor mange trafikanter som befinner seg på nedstrømssiden av brannen [ ]
- Annet (beskriv) [ ]

Du har nå ankommet utsiden av Byfjordtunnelen og skal inn for å gjøre innsats. Hva er dine prioriteringer i denne fasen?

- Jeg forsikrer meg om at jeg har forstått oppdraget [ ]

- Jeg fortsetter å søke oppdatert informasjon [ ]
- Jeg forsikrer meg om at det ikke er personskader med behov for øyeblikkelig hjelp ved utsiden av tunnelen [ ]
- Jeg forsikrer meg om at møtende trafikk evakuerer tunnelen og parkert trafikk er kontrollert [ ]
- Jeg forsikrer meg om at brann- og slokkingsressurser er tilstede på nordsiden av tunnelen [ ]
- Jeg stiller spørsmål om VTS har utført innsnakk på DAB [ ]
- Annet (beskriv) [ ]

Du har nå ankommet brannstedet og skal iverksette innsats. Hva er dine prioriteringer i denne fasen?

- Jeg starter livreddende arbeid for personer i umiddelbar nærhet [ ]
- Jeg starter søk og redning [ ]
- Jeg starter slangeutlegg og sikring [ ]
- Jeg starter slukking av brannen [ ]
- Jeg søker informasjon om eventuelle kjøretøy og last som står forlatt i tunnelen nedstrøms for brannen [ ]
- Jeg tenker på forhold som har betydning for min egen sikkerhet [ ]
- Annet (beskriv) [ ]

Scenario 2

Hendelse rapportert inn fra innringer til 110 sentralen – fredag 03. juli 2020, kl. 09.45.

- Varsel om kraftig røykutvikling i vogntog i Mastrafjordtunnelen.
- Innringer melder at vogntoget er på vei nord, i stigning mot Rennesøy. Han antar at vogntoget befinner seg ca. 1 - 1,5 km fra tunnelmunningen.
- Kl. 09.47. VTS observerer at føreren av vogntoget trekker ut et brannslukningsapparat og forsøker å slukke brannen.

- På dette tidspunktet melder VTS om flere kjøretøy på vei ned mot brannstedet.
- 110 sentralen trippelvarsler og VTS stenger tunnelen i henhold til prosedyre for brann i kjøretøy.
- Brannventilasjonen starter i henhold til prosedyre.
- Kl. 09.48. VTS melder at vogntoget er umerket og har ukjent last.
- Det meldes også at en turistbuss som tilhører reiseselskapet Belgium Senior Travels har stanset ca. 200 meter nord for vogntoget grunnet kø, samt at flere kjøretøy står parkert nærme brannstedet.
- Kl. 09.49. VTS melder stans i trafikken.
- Kl. 09.50. VTS observerer ca. 15 - 20 personer gående inne i tunnelen, i retning nord.
- Kl. 09.51. Brann- og røykutviklingen tiltar.
- På dette tidspunktet har VTS mistet bildet i området hvor vogntoget befinner seg og har svært begrenset sikt nedstrøms for brannen.

Åpent spørsmål (skriv tydelig, gjerne med blokkbokstaver):

Du har fått denne informasjonen og er nå på vei mot brannstedet. Hva er dine hovedbekymringer? Beskriv tre aktiviteter som ifølge deg bør ha høyest prioritet i denne fasen for å håndtere hendelsen.

Bekymringer knyttet til hendelsen

3 aktiviteter knyttet til håndtering av hendelsen:

Med bakgrunn i denne informasjonen, hva er dine prioriteringer i de ulike fasene presentert nedenfor? Ranger fem av svaralternativene, hvor 1 betyr høyest prioritet og 5 lavest.

Du befinner deg i mannskapsbilen, på vei mot hendelsen. Det tar ca. 17 minutter å ankomme brannstedet. Hva er dine prioriteringer i denne første fasen?

- Jeg søker informasjon fra min nærmeste leder om hva som brenner, hvor det brenner og hvor mange trafikanter som befinner seg i tunnelen [ ]
- Jeg avstemmer med mine kollegaer potensielle farer ved innsatsen [ ]
- Jeg avstemmer med mine kollegaer mulig innsatstaktikk [ ]
- Jeg får bekreftet fra min nærmeste leder at ventilasjonen går i forhåndsdefinert retning [ ]
- Jeg søker informasjon om hvor mange trafikanter som befinner seg på nedstrømssiden av brannen [ ]
- Jeg stiller spørsmål om hvilke handlinger VTS har utført [ ]
- Annet (beskriv) [ ]

Du har nå ankommet utsiden av Mastrafjordtunnelen og skal inn for å gjøre innsats. Hva er dine prioriteringer i denne fasen?

- Jeg forventer tydelig mål med innsats/ taktisk plan fra min nærmeste leder [ ]
- Jeg ønsker å få oppdatert informasjon om utviklingen av brannen [ ]
- Jeg forsikrer meg om at det ikke er personskader med behov for øyeblikkelig hjelp ved utsiden av tunnelen [ ]
- Jeg forsikrer meg om at møtende trafikk evakuerer tunnelen og parkert trafikk er kontrollert [ ]
- Jeg forsikrer meg om at brann- og slokkingsressurser er tilstede på nordsiden av tunnelen [ ]
- Jeg forsikrer meg om at både tankbil og ytterligere brann- og slokkingsressurser er på vei [ ]
- Annet (beskriv) [ ]

Du har nå ankommet brannstedet og skal iverksette innsats. Hva er dine prioriteringer i denne fasen?

- Jeg starter livreddende arbeid for personer i umiddelbar nærhet [ ]
- Jeg starter slangeutlegg og sikring [ ]

- Jeg iverksetter slukking av brannen [ ]
- Jeg innhenter informasjon om eventuelle kjøretøy og last som står forlatt i tunnelen nedstrøms for brannen [ ]
- Jeg tenker på forhold som har betydning for min egen sikkerhet [ ]
- Jeg søker oppdatert informasjon fra nordsiden [ ]
- Annet (beskriv) [ ]

Appendix C – Actual competence investigation for operational leaders

Du er stasjonert på Kvernevik brannstasjon og har førsteinnsats i begge scenariene beskrevet nedover. Din rolle er utrykningsleder. Besvarelsen skal ta utgangspunkt i tilgjengelige ressurser fra Kvernevik brannstasjon.

Scenario 1

Hendelse rapportert inn fra VTS til 110 sentralen - mandag 03. februar 2020, kl. 07.15.

- Varsel om røykutvikling og flammer i stor varebil. Kjøretøyet har stoppet i en havarinisje i bunnen av Byfjordtunnelen, i retning sør mot Randaberg.
- Kl. 07.16. VTS observerer at bilføreren trekker ut et brannslukningsapparat og forsøker å slukke brannen.
- 110 sentralen trippelvarsler og VTS stenger tunnelen i henhold til prosedyre for brann i kjøretøy.
- Brannventilasjon starter i henhold til prosedyre.
- Innringer melder at kjøretøyet tilhører Riska Sveis AS.
- Grunnet kraftig røykutvikling og brann, kl. 07.18. danner det seg kø bak kjøretøyet som brenner, i retning sør.
- Kl. 07.19. VTS melder å ha mistet bildet fra flere av kameraene nedstrøms for kjøretøyet, og at det blir mindre sikt på resterende kamera i retning nord.
- På dette tidspunktet befinner flere kjøretøy seg på vei ned mot brannen fra begge sider.
- Kl. 07.20. VTS melder at det observeres 4 vogntog ca. 200 meter sør for brannen. Disse har stilt seg i vegkanten av sitt kjørefelt med varsellys på.
- VTS melder også at det observeres 3 personbiler mellom disse vogntogene.

Åpent spørsmål (skriv tydelig, gjerne med blokkbokstaver):

Du har fått denne informasjonen og er nå på vei mot brannstedet. Hva er dine hovedbekymringer? Beskriv tre aktiviteter som ifølge deg bør ha høyest prioritet i denne fasen for å håndtere hendelsen.

Bekymringer knyttet til hendelsen:

3 aktiviteter knyttet til håndtering av hendelsen:

Med bakgrunn i denne informasjonen, hva er dine prioriteringer i de ulike fasene presentert nedenfor? Ranger fem av svaralternativene, hvor 1 betyr høyest prioritet og 5 lavest.

Du befinner deg i mannskapsbilen, på vei mot hendelsen. Det tar ca. 7 minutter å ankomme brannstedet. Hva er dine prioriteringer i denne første fasen?

- Jeg innhenter informasjon om hva som brenner, hvor det brenner og hvor mange trafikanter som befinner seg i tunnelen [ ]
- Jeg innhenter informasjon om hvor mange trafikanter som befinner seg på nedstrømssiden av brannen [ ]
- Jeg etablerer dialog med andre utrykkende enheter [ ]
- Jeg forsikrer meg om at mannskapet har lik situasjonsforståelse [ ]
- Jeg får bekreftet hvor mye brann- og slokkingsressurser som er på vei [ ]
- Jeg får bekreftet ventilasjonsretning fra VTS og 110 sentralen [ ]
- Annet (beskriv) [ ]

Du har nå ankommet utsiden av Byfjordtunnelen og skal inn for å gjøre innsats. Hva er dine prioriteringer i denne fasen?

- Jeg ber VTS og 110 sentralen om å formidle kamerainformasjon [ ]
- Jeg ber VTS om å utføre innsnakk på DAB [ ]

- Jeg forsikrer meg om at møtende trafikk evakuerer tunnelen og parkert trafikk er kontrollert [ ]
- Jeg oppretter ILKO [ ]
- Jeg forsikrer meg at det ikke er personskader med behov for øyeblikkelig hjelp ved utsiden av tunnelen [ ]
- Jeg oppretter kontakt med brann- og slokkingsressurser på nordsiden av tunnelen [ ]
- Annet (beskriv) [ ]

Du har nå ankommet brannstedet og skal iverksette innsats. Hva er dine prioriteringer i denne fasen?

- Jeg kontakter kjentmann/ sjåføren for å innhente relevant informasjon [ ]
- Jeg starter livreddende arbeid for personer i umiddelbar nærhet [ ]
- Jeg vurderer nøye forhold som har betydning for mannskapenes sikkerhet [ ]
- Jeg innhenter informasjon om eventuelle kjøretøy og last som står forlatt i tunnelen nedstrøms for brannen [ ]
- Jeg formidler oppdatert informasjon til resten av mannskapene [ ]
- Jeg gir vindusmelding/ 98-melding i felles talegruppe [ ]
- Annet (beskriv) [ ]

Scenario 2

Hendelse rapportert inn fra innringer til 110 sentralen – fredag 03. juli 2020, kl. 09.45.

- Varsel om kraftig røykutvikling i vogntog i Mastrafjordtunnelen.
- Innringer melder at vogntoget er på vei nord, i stigning mot Rennesøy. Han antar at vogntoget befinner seg ca. 1 - 1,5 km fra tunnelmunningen.

- Kl. 09.47. VTS observerer at føreren av vogntoget trekker ut et brannslukningsapparat og forsøker å slukke brannen.
- På dette tidspunktet melder VTS om flere kjøretøy på vei ned mot brannstedet.
- 110 sentralen trippelvarsler og VTS stenger tunnelen i henhold til prosedyre for brann i kjøretøy.
- Brannventilasjonen starter i henhold til prosedyre.
- Kl. 09.48. VTS melder at vogntoget er umerket og har ukjent last.
- Det meldes også at en turistbuss som tilhører reiseselskapet Belgium Senior Travels har stanset ca. 200 meter nord for vogntoget grunnet kø, samt at flere kjøretøy står parkert nærme brannstedet.
- Kl. 09.49. VTS melder stans i trafikken.
- Kl. 09.50. VTS observerer ca. 15 - 20 personer gående inne i tunnelen, i retning nord.
- Kl. 09.51. Brann- og røykutviklingen tiltar.
- På dette tidspunktet har VTS mistet bildet i området hvor vogntoget befinner seg og har svært begrenset sikt nedstrøms for brannen.

Åpent spørsmål (skriv tydelig, gjerne med blokkbokstaver):

Du har fått denne informasjonen og er nå på vei mot brannstedet. Hva er dine hovedbekymringer? Beskriv tre aktiviteter som ifølge deg bør ha høyest prioritet i denne fasen for å håndtere hendelsen.

Bekymringer knyttet til hendelsen:

3 aktiviteter knyttet til håndtering av hendelsen:

Med bakgrunn i denne informasjonen, hva er dine prioriteringer i de ulike fasene presentert nedenfor? Ranger fem av svaralternativene, hvor 1 betyr høyest prioritet og 5 lavest.

Du befinner deg i mannskapsbilen, på vei mot hendelsen. Det tar ca. 17 minutter å ankomme brannstedet. Hva er dine prioriteringer i denne første fasen?

- Jeg ber VTS om å utføre innsnakk på DAB for trafikanter som befinner seg nedstrøms for brannen [ ]
- Jeg innhenter informasjon om hva som brenner, hvor det brenner og hvor mange trafikanter som befinner seg i tunnelen [ ]
- Jeg innhenter informasjon om hvor mange trafikanter som befinner seg på nedstrømssiden av brannen [ ]
- Jeg får bekreftet hvor mye brann- og slokkingsressurser som er på vei og eventuelt ber om styrking [ ]
- Jeg ber om bekreftelse fra VTS eller 110 sentralen om brannventilasjonen ivaretar oppstrømssiden av brannen [ ]
- Jeg etablerer dialog med andre utrykkende enheter [ ]
- Annet (beskriv) [ ]

Du har nå ankommet utsiden av Mastrafjordtunnelen og skal inn for å gjøre innsats. Hva er dine prioriteringer i denne fasen?

- Jeg forsikrer meg at mannskapene sitter med lik situasjonsforståelse [ ]
- Jeg forsikrer meg om at møtende trafikk evakuerer tunnelen og parkert trafikk er kontrollert [ ]
- Jeg kommuniserer til mannskapet mål med innsatsen / taktisk plan [ ]
- Jeg forsikrer meg om at det ikke er personskader med behov for øyeblikkelig hjelp ved utsiden av tunnelen [ ]
- Jeg oppretter kontakt med brann- og slokkingsressurser på nordsiden av tunnelen [ ]
- Jeg ber om bekreftelse om hvordan helse og politi etablerer sine ressurser [ ]
- Annet (beskriv) [ ]

Du har nå ankommet brannstedet og skal iverksette innsats. Hva er dine prioriteringer i denne fasen?

- Jeg vurderer nøye forhold som har betydning for mannskapenes sikkerhet [ ]
- Jeg avklarer mål med innsats til brannressurser på vei til hendelsen [ ]
- Jeg starter livreddende arbeid for personer i umiddelbar nærhet [ ]
- Jeg kontakter kjentmann/ sjåføren for å innhente relevant informasjon [ ]
- Jeg formidler oppdatert informasjon til resten av mannskapene [ ]
- Jeg innhenter informasjon på skadestedet om eventuelle kjøretøy og last som står forlatt i tunnelen nedstrøms for brannen [ ]
- Annet (beskriv) [ ]

Appendix D – Self-evaluation questionnaire prior to and after the course

Vurderingen rangeres på en femtrinnsskala hvor 1 er svært liten grad, 2 liten grad, 3 noen grad, 4 høy grad og 5 svært høy grad.

Vi ønsker at du selv vurderer din kunnskap og kompetanse innen tunnelbrannsikkerhet.

Deltakerens navn:

1. I hvilken grad kjenner du til grunnleggende forebyggende arbeid med tunnelsikkerhet?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

2. I hvilken grad kjenner du til tunnelenes beredskapsplaner og objektplaner?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

3. I hvilken grad kan du vurdere muligheter for innsats med utgangspunkt i tunnelens infrastruktur?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

4. I hvilken grad kan du vurdere utfordringer, farer og restriksjoner for innsats med utgangspunkt i skadestedsfaktorer?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

5. I hvilken grad kan du iverksette og gjennomføre sikker innsats ved hendelse i tunnel?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

6. I hvilken grad kan du vurdere ulike tiltak som ikke utsetter innsatspersonell og/eller publikum for farer med utgangspunkt i brannens oppstrøm- og nedstrøms side?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

7. I hvilken grad kjenner du til fordeler og ulemper ved bruk av brannventilasjon i tunnel?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

8. I hvilken grad kan du innhente informasjon, sortere informasjon, tolke informasjon og forutse sannsynlig utvikling av en hendelse?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

9. I hvilken grad kan du vurdere ulike handlingsalternativer, sikkerhetstiltak og identifisere risikofaktorer?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

10. I hvilken grad kan du iverksette tiltak og vurdere deres effektivitet?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

11. I hvilken grad kan du vurdere muligheter og begrensninger knyttet til taktikk og teknikk ved innsats i tunnel?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

12. I hvilken grad kan du formidle nøkkelinformasjon og taktiske instruksjoner på en rask og tydelig måte?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

13. I hvilken grad kan du vurdere ressursbehov og innsatstaktikk med utgangspunkt i innhentet informasjon?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

14. I hvilken grad kan du vurdere tiltak tilpasset utviklingen av situasjonen?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

15. Tenk deg at du blir kalt ut til innsats på grunn av en stor tunnelbrann. I hvilken grad er du kompetent til å kunne håndtere en slik situasjon?

(1) ❑ (2) ❑ (3) ❑ (4) ❑ (5) ❑

Åpent spørsmål:

Hva ønsker du å jobbe mer med for å videre utvikle din kompetanse i tunnelbrannsikkerhet?

Appendix E – Interview guide for participants

Hvilke forventninger hadde du til kurset?

Gjorde du en viss forberedelse i forkant av kurset?

I hvor stor grad skapte opplæringsaktivitetene forståelse for beslutninger knyttet til sikker iverksettelse av innsats?

I hvor stor grad skapte opplæringsaktivitetene forståelse for begrensninger og muligheter knyttet til innsats med utgangspunkt i tunnelenes infrastruktur?

I hvor stor grad skapte opplæringsaktivitetene forståelse for begrensninger og muligheter knyttet til innsats med utgangspunkt i kjennetegn ved situasjonen?

I hvor stor grad gav opplæringsaktivitetene innsikt i kommunikasjonsutfordringer som kan oppstå ved en reell hendelse i tunnel?

I hvor stor grad gav opplæringsaktivitetene innsikt i hvordan tiltak kan tilrettelegges for å ivareta selvredningsprinsippet?

I hvor stor grad opplevde du scenariene under de praktiske øvelsene til å være i overenstemmelse med det du sannsynligvis vil møte i en reell hendelse i tunnel?

I hvor stor grad opplevde du omgivelsene rundt opplæringssituasjonen til å fremme læring?

Hva har vært din personlige motivasjon for å delta på kurset?

I hvilken grad opplevde du innholdet i kurset som utfordrende i forhold til din egen kompetanse?

I hvor stor grad hadde instruktørene de nødvendige kvalifikasjoner i forhold til det som ble undervist?

Hva har vært instruktørenes bidrag i forhold til ditt læringsutbytte?

I hvilken grad opplevde du det sosiale klimaet under de ulike opplæringsaktivitetene til å fremme læring?

I hvor stor grad opplevde du opplæringsaktivitetene til å skape muligheter for samhandling mellom deltakerne for å løse spesifikke oppgaver?

I hvor stor grad har den praktiske delen av opplæringsaktivitetene lagt til rette for evaluering av informasjon for å fremme gode beslutninger ved en reell hendelse i tunnel?

I hvor stor grad har den praktiske delen av opplæringsaktivitetene skapt forståelse for hvordan ressurser kan best mulig brukes og prioriteres ved en reell hendelse i tunnel?

I hvor stor grad har den praktiske delen av opplæringsaktivitetene skapt forståelse for hvordan ansvar og rolleforståelse ved en reell hendelse i tunnel skal fordeles?

I hvor stor grad brukte du informasjon formidlet under den teoretiske delen av opplæringsaktivitetene til å løse spesifikke utfordringer i de praktiske øvelsene?

I hvor stor grad brukte du evnen til å foreta mentale simuleringer under de praktiske øvelsene for å løse spesifikke oppgaver?

I hvor stor grad har opplæringsaktivitetene medført noen form for endringer?

Hva vil du gjøre annerledes enn det du har gjort før? Hva slags endringer kommer det til å skje og hvorfor?

I hvor stor grad har opplæringsaktivitetene medført noen form for bekreftelse? Var det noe som fungerte bra og som er verdt å ta med videre?

I hvor stor grad har opplæringsaktivitetene gitt mer dybde og dermed skapt dypere forståelse for et spesifikt fenomen?

Har kurset innfridd dine forventninger? Eventuelt, har du forslag til hvordan kurset kan bli forbedret?

Er det noe spesielt du sitter igjen med av kunnskaper og ferdigheter i etterkant av kurset?

Har du tenkt på hvordan du skal ta inn ervervet kunnskap videre i organisasjonen?

Appendix F – NSD

NSD NORSK SENTER FOR FORSKNINGSDATA

NSD sin vurdering

Prosjekttittel

Tunneler, sikkerhets- og beredskapsopplæring i brann- og redningstjenesten: utvikling av kunnskap og kompetanse for forebyggende og beredskapspersonell.

Referansenummer

383100

Registrert

11.01.2019 av Gabriela Bjørnsen - gabriela.bjornsen@rogbr.no

Behandlingsansvarlig institusjon

Universitetet i Stavanger / Det samfunnsvitenskapelige fakultet / Institutt for medie-, kultur- og samfunnsfag

Prosjektansvarlig

Gabriela Bjørnsen, gabriela.bjornsen@rogbr.no, tlf: 93458705

Type prosjekt

Forskerprosjekt

Prosjektperiode

01.09.2018 - 31.08.2021

Status

29.01.2019 - Vurdert anonym

Vurdering (1)

29.01.2019 - Vurdert anonym

Basert på informasjonen i meldeskjemaet forstår vi det slik at det ikke skal behandles direkte eller indirekte opplysninger som kan identifisere enkeltpersoner i dette prosjektet, så fremt det gjennomføres i tråd med det som er dokumentert i meldeskjemaet 29.01.2019 med vedlegg. Prosjektet trenger derfor ikke en vurdering fra NSD.

HVA MÅ DU GJØRE DERSOM DU LIKEVEL SKAL BEHANDLE PERSONOPPLYSNINGER?
Dersom prosjektopplegget endres og det likevel blir aktuelt å behandle personopplysninger må du melde dette til NSD ved å oppdatere meldeskjemaet. Vent på svar før du setter i gang med behandlingen av personopplysninger.

VI AVSLUTTER OPPFØLGING AV PROSJEKTET
Siden prosjektet ikke behandler personopplysninger avslutter vi all videre oppfølging.

NSD NORSK SENTER FOR FORSKNINGSDATA

NSD sin vurdering

Prosjekttittel

«Tunneler, sikkerhets- og beredskapsopplæring i brann og redningstjenesten; utvikling av kunnskap og kompetanse».

Referansenummer

983238

Registrert

19.10.2021 av Gabriela Bjørnsen - gabriela.bjornsen@rogbr.no

Behandlingsansvarlig institusjon

Universitetet i Stavanger / Det teknisk- naturvitenskapelige fakultet / Institutt for sikkerheit, økonomi og planlegging

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)

Gabriela Bjørnsen , gabriela.bjornsen@rogbr.no, tlf: 93458705

Type prosjekt

Forskerprosjekt

Prosjektperiode

30.10.2021 - 30.08.2022

Status

21.10.2021 - Vurdert

Vurdering (1)

21.10.2021 - Vurdert

Det er vår vurdering at behandlingen av personopplysninger i prosjektet vil være i samsvar med personvernlovgivningen så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet med vedlegg den 21.10.2021, samt i meldingsdialogen mellom innmelder og NSD. Behandlingen kan starte.

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle alminnelige kategorier av personopplysninger frem til 30.08.2022.

LOVLIG GRUNNLAG
Prosjektet vil innhente samtykke fra de registrerte til behandlingen av personopplysninger. Vår vurdering er at prosjektet legger opp til et samtykke i samsvar med kravene i art. 4 og 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse som kan dokumenteres, og som den registrerte kan trekke tilbake.

Lovlig grunnlag for behandlingen vil dermed være den registrertes samtykke, jf. personvernforordningen art. 6 nr. 1 bokstav a.

PERSONVERNPRINSIPPER
NSD vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen om:

- lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen
- formålsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formål, og ikke behandles til nye, uforenlige formål
- dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet
- lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formålet

DE REGISTRERTES RETTIGHETER
Så lenge de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18), og dataportabilitet (art. 20).

NSD vurderer at informasjonen om behandlingen som de registrerte vil motta oppfyller lovens krav til form og innhold, jf. art. 12.1 og art. 13.
Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned.

FØLG DIN INSTITUSJONS RETNINGSLINJER
NSD legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).

Ved bruk av databehandler (spørreskjemaleverandør, skylagring eller videosamtale) må behandlingen oppfylle kravene til bruk av databehandler, jf. art 28 og 29. Bruk leverandører som din institusjon har avtale med.

For å forsikre dere om at kravene oppfylles, må dere følge interne retningslinjer og/eller rådføre dere med behandlingsansvarlig institusjon.

MELD VESENTLIGE ENDRINGER
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til NSD ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilke type endringer det er nødvendig å melde: https://www.nsd.no/personverntjenester/fylle-ut-meldeskjema-for-personopplysninger/melde-endringer-i-meldeskjema
Du må vente på svar fra NSD før endringen gjennomføres.

OPPFØLGING AV PROSJEKTET
NSD vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Lykke til med prosjektet!