Myndigheten för samhällsskydd och beredskap

STUDY

Knowledge review

– How to make first responders protected, connected and fully aware of risks and threats at the incident site

Abstract

Knowledge review - How to make first responders protected, connected and fully aware of risks and threats at the incident site.

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Swedish Defence Research Agency - FOI

Charlotte Stenius & Mari Olsén

This study is a knowledge review of scientific research, development and innovation in the area of protection of first responders at incident sites. The specific aim of the study was to search for research connected to three capability gaps identified within the international cooperation International Forum to Advance First Responder Innovation (IFAFRI). The three capability gaps include the ability to, in real time; 1) in real-time know the location of first responders and their proximity to risks and hazards, 2) in real-time detect, monitor, and analyze passive and active threats and hazards at incident scenes and 3) to rapidly identify hazardous agents and contaminants. The study was divided into three parts; a review of scientific research, workshops with subject matter experts (SMEs) at the Swedish Defence Research Agency, FOI, and a review of innovations and products available on the Swedish market.

MSB:s contact:

Yvonne Näsman, +4610-240 40 30

Eleonor Storm, +4610-240 53 76

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Preface

In order to be able to coordinate the development within the Swedish rescue services effectively, the Swedish Civil Contingencies Agency (MSB) needs to have an overview of the research and development that has been carried out in Sweden and internationally. There are currently overviews of research and development in certain areas, but there is not a comprehensive picture of the research situation in the entire rescue services area. It has become particularly clear in dialogues concerning development needs nationally but also in MSB's international work and in connection with the establishment of the innovation mechanism.

In order for rescue operations to be carried out in a safe and efficient manner, it is important that the knowledge development carried out within Sweden is not done in areas that are already developed by others. Decisions that arelargely based on easily accessible and quality-assured knowledge increase the ability to contribute in a cost-effective manner to the development of the rescue services ability to carry out efficient and safe rescue operations.

The aim of this study has been to compile the research and development that has been carried out within the three sub-areas protected, connected and fully aware. The focus has been the area protected, which includes protective clothing and other protection at the incident scene in both national and international research studies and development projects.

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Summary

This knowledge review is an overview of the current state of research and development within the field of protection for first responders at the incident site. The purpose is to give the Swedish Civil Contingency Agency (MSB) a better view of research that has already been carried out, is under implementation or is being developed. The research and development presented in this report are linked to the areas Protected, Connected and Fully aware, and are particularly focused on three capability gaps. These are the ability to: 1) in real time know the location of the first responders and their proximity to risks and hazards, 2) in real-time detect, monitor and analyze passive and active threats and hazards at incident scenes, and 3) rapidly identify hazardous agents and contaminants. This report presents the methods used for acquiring research and development projects, as well as an overview of projects, products and collaborations. The complete findings are presented in a separate document to the Swedish Civil Contingency Agency.

A purpose of this knowledge review was to identify research and development projects that focused on the three capability gaps. The findings showed that the capability gaps are mainly found in the area Protected. The results of this study show a higher proportion of research and development in the area Protected. The research in the areas Connected and Fully aware are not as closely linked to first responders as in the area Protected. Some research and development is aimed at including the areas Connected and Fully aware in order to develop a solution that, for example, incorporates the whole chain of events starting with a sensor, through a wireless network, and ending up as decision support for the incident commander.

In the identified research projects, the developed equipment mainly consisted of prototypes demonstrating how the technology can be used. Difficulties have arisen when investigating what happens to the prototype at the end of the project, whether it is developed further or not. A few products were identified that are under commercial development or are already available on the market. The reason to why only a few products were identified could be that a lot of the technology is new, and private development projects are not as open or as widely reported as research projects.

1. Introduction

Incidents, such as fires, traffic accidents or other events, are dangerous by nature. Rescue operations therefore need to be conducted in a manner that minimizes the risk of death and injuries to first responders. Ways to minimize causalities include development of personal protection equipment (PPE), applying methods for risk assessment, or managing the risks. Both the society and the equipment are developing, which leads to new risks, but also new ways to manage the risk and protect first responders. To be able to coordinate research and knowledge development in the field of rescue operations, it is important for the Swedish Civil Contingencies Agency to know what research has already been performed. Decisions on further research and knowledge development activities, grounded on a validated knowledge basis, increase the ability to make priorities regarding what is needed to make first responders safe during rescue operations.

A collective work regarding PPE for first responders is carried out in the bilateral cooperation between the Swedish Civil Contingencies Agency and the US Department of Homeland Security. In relation to that work, the bilateral cooperation has identified that there is no overview of what research has been conducted in the field of first responders and their protection at the incident site.

In the United States there is a five-year development program (commenced in 2015) for the Next Generation First Responders (DHS, 2018). The focus is on new technology, and the research and development is divided into the areas Protected, Connected and Fully aware. The areas are defined by the department of Homeland Security (DHS, 2018) as follows:

> **Protected**, which entails protection in the form of personal protective equipment, e.g., thermal clothing It also includes sensors that detect risks in the surroundings or keep track of the personnel.
>
> **Connected**, which is about connecting personnel at the incident site with each other. It also entails connecting information from the incident site to an emergency operations center (EOC).
>
> **Fully aware***,* which is about sensemaking and awareness about a risk detected by a sensor or a colleague at the incident site. Personnel could become aware of dangers through warning systems or decision support systems.

In addition, in the international cooperation *International Forum to Advance First Responder Innovation (IFAFRI),* where the Swedish Civil Contingencies Agency is a member, three capability gaps related to the three mentioned areas have been identified:

1. The ability to know the location of responders and their proximity to risks and hazards in real time.

2. The ability to detect, monitor and analyze passive and active threats and hazards at incident scenes in real time.
3. The ability to rapidly identify hazardous agents and contaminants.

1.1 Description of research area

First responders take great risks when trying to save people, property or the environment. The risks are minimized by using suitable protective equipment and validated methods. How rescue operations are carried out varies, depending on the event and organization culture. For example, in construction fires there is both an offensive approach and a defensive approach. If there are lives to save, an offensive approach is more likely to be chosen. If only property is at stake, a more defensive approach is more likely to be used, i.e., not sending fire fighters into a burning building.

Countries as well as organizations collect statistics of line of duty deaths (LODD) for fire fighters. The Federal Emergency Management Agency (FEMA) reported that in the United States of America 87 fire fighters died on duty in 2017, 40 of them during an emergency response. Of these, ten died during a construction fire and seven during a forest fire. The other fatalities involved trauma and, in most cases, vehicles (FEMA, 2018). Between 2000 and 2017, ten LODDs occurred in Sweden. Of these, seven occurred when working at traffic incidents or when responding to incidents. One of these LODDs was a fire fighter who died in a construction fire in 2003 (Svensson, 2017).

1.1.1 Type of accidents

To create an understanding of what kind of situations first responders, particularly firefighters, encounter and what kind of protection that is needed, a few scenarios were considered for this report.

Construction fire

Construction fires are one of the most common types of accidents among firefighters and probably the first that springs to mind. Different types of risks are associated with construction fires. First, the building construction could be of varying difficulty, both in terms of how the fire is spreading and how easy it is for firefighters to find their way, or if there are other risks such as gas cylinders that could explode. Second, the fire causes risks with regard to low visibility and heat. The fire also affects a construction, thus increasing the risk for the building to collapse.

Traffic accidents

According to the statistics of LODDs in Sweden, traffic accidents are among the riskiest assignment for a firefighter, both in terms of responding to incidents and working at traffic accidents (Svensson, 2017). When responding to accidents, the responders are at risk of a traffic accident themselves. On the incident scene, the risks for first responders include both traffic and operational duties that could cause a trauma.

Wildfire

One of the main problems with wildfires is the widespread area. It is problematic to know where first responders are located, which could be a great risk should the wind turn and create fast spreading fires. The positional information is needed to both warn and rescue first responders who are at risk.

Terrorism

Incidents caused by a terrorist attack could vary in character. For example, there could be explosions with collapsed buildings, unexploded IEDs or ongoing shootings. These scenarios require first responders to be aware of the surroundings at the same time as probably being faced with a large number of victims. One scenario that could pose a further risk is if the terrorists are still at the scene or have placed other detonations with the purpose to hurt and kill first responders.

Chemical accidents

Various hazardous materials are transported by road or stored and used in industries. Chemicals that are spreading could be dangerous to both first responders and civilians, but the first responders might still have to come close to the source to be able to stop the spread. It could also be the case that there is no leakage at first, but that it occurs while first responders are at the site of the accident. They therefore need to be warned, either in order to get away safely or to manage the situation.

1.2 Purpose

The purpose of the present study, "FOI-2018-954:5/MSB 2018-05091",is to give the Swedish Civil Contingency Agency a better view of the research that has already been carried out, is under implementation, or is being developed. The development of research and knowledge is linked to the areas Protected, Connected and Fully aware. There is also a special focus on the three capability gaps, the ability to: 1) in real time know the location of first responders and their proximity to risks and hazards, 2) in real-time detect, monitor, and analyze passive and active threats and hazards at incident scenes, and 3) rapidly identify hazardous agents and contaminants. In addition, the purpose of the study is to investigate if there is research with a special focus on gender and differences in protection between men and women, and if adaptations are required.

The purpose of this report is to provide a summary of the research and development carried out in the areas Protected, Connected and Fully aware. This report presents the methods used for acquiring research and development projects and provides an overview of a few projects, products and cooperations. The complete findings are presented in a separate document to the Swedish Civil Contingency Agency.

1.3 Limitations

The study was designed to have a wide span of research and development rather than depth. The working procedure was to read the abstracts of publications and only a few times the publications were read to get a better idea of the content of the study. Since only abstracts and summaries from publications and projects have been read, the analysis in this report does not contain a full assessment of their relevance to the areas Protected, Connected and Fully aware.

The results are based on research and development carried out in the last ten years (2007-2018). Results from this timespan were considered relevant and of interest to the Swedish Civil Contingency Agency. The report only summarizes a subset of all projects, products and innovations identified during the study. Some examples of projects or products that are of great relevance to the purpose of the study are given within each subcategory. They are presented briefly without valuation of pros and cons.

1.4 Abbreviations and definitions

BA – Breathing Apparatus

BIM – Building Information Modeling

Crowdsourcing - A method where public knowledge is used to control/verify/build information. For example Wikipedia.

DHS – Department of Homeland Security

EOC – Emergency Operations Center

EU – European Union

FEMA – Federal Emergency Management Agency

First responder –In this report, this primarily refers to firefighters, but it can also include police, paramedics, etc.

GIS – Geographic Information System

GPS – Global Positioning System

GSM – Groupe Spécial Mobile

IED - Improvised Explosive Devices

IoT – Internet of Things

LODD – Line of Duty Death

MSB - the Swedish Civil Contingency Agency.

PAN – Personal Area Network

PPE – Personal Protective Equipment

PPDR – Public Protection and Disaster Relief

SOP – Standard Operational Procedure

SME – Subject Matter Expert

TAMSEC – National symposium on Technology and Methodology for Security and Crisis Management

UAV – Unmanned Aerial Vehicle

2. Method

The strategic approach for this work was divided into three parts (the grey boxes in Figure 1). The first step consisted of a compilation and analysis based on three different information sources: scientific publications, research projects and development of products on the market. The information was then divided into the three areas Protected, Connected and Fully aware. The gathered information was validated and more information was then added in workshops with Subject Matter Experts (SMEs). This led to a final mapping of research and development in the three areas Protected, Connected and Fully aware (Figure 2).

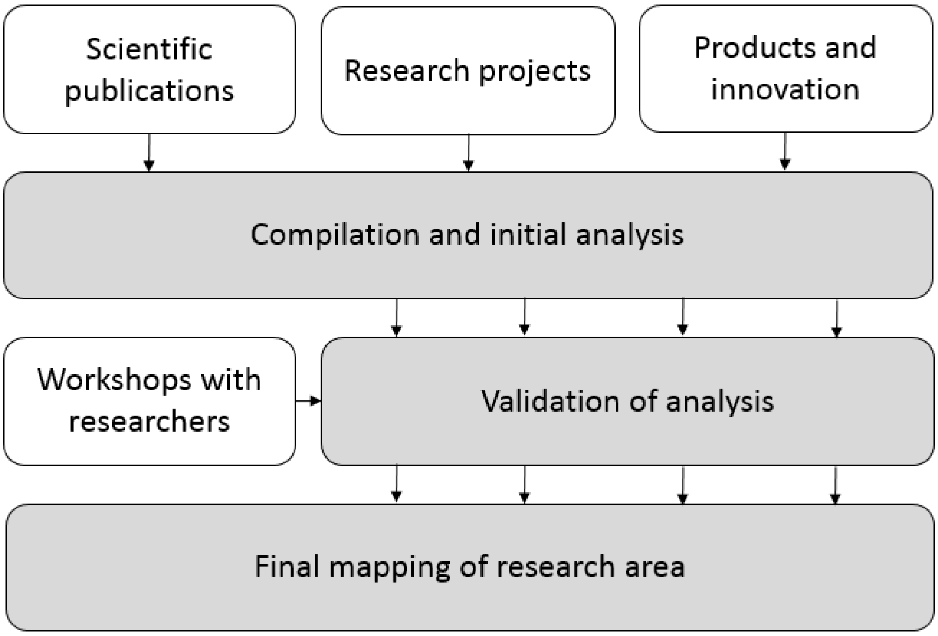

Figure 1. Strategic approach for the knowledge review.

2.1 Information acquisition

In this section, the different stages of the strategic approach are described. A number of search terms (see Table 1) were generated based on discussions about the capability gaps defined in the introduction, as well as types of accidents that were applicable to this report. All words were used in the search for scientific research and a few selected words were used in other searches (see further details below).

Only results that were associated with Protected, Connected and Fully aware were included. All research and development projects, products and scientific publications that were found in searches and in workshops were listed in a separate document. Only a few representative studies are described in this report (see Results). Search methods and workshops are described in further detail below.

2.1.1 Scientific publications

To identify scientific publications, a search in the database Scopus was conducted. Scopus is a multi-disciplinary database widely used for literature reviews and has been proven to result in a sufficient dataset, which motivates the use of the database.

The first Boolean search in Scopus was based on 28 words/search term (see Table 1), and resulted in 789 publications during the time span 2013-2018. Publications in other languages than English and Swedish were excluded. All abstracts were then read, and studies that had no relevance to the three areas (Protected, Connected and Fully aware), or first responders were excluded. The remaining 108 publications were divided into the areas Protected, Connected and Fully aware, and specified by subcategories. The included publications led to a first analysis of the field and the continued focus of the study.

Table 1. Search terms used when searching scientific literature. The search was performed with AND between columns and OR within columns.* includes all abbreviations.

Area/Actor	Equipment	Activity
Fire ground	Sensor*	Tracking
First responders	Body-worn system	Positioning
*Officer	Surveillance systems	Localization
*Commander	Equipment	Monitoring
Fire fighter	Person* Protective equipment	Physiological parameters
Rescue worker	Personal area network	Environmental parameters
Rescue site	Communication technologies	Alerting
Fire and rescue service	Safety equipment	Situation awareness
Emergency service		Securing
		Indicating
		Protect*

A second search with an extended time span (2007-2018) and the same search terms, was carried out by request of the Swedish Civil Contingencies Agency. Literature in other languages than English and Swedish was excluded. In Scopus, literature is sorted by subject areas and include keywords of the publications. To avoid publications not related to the area of interest, a few keywords and subject areas were excluded (see Table 2). The search resulted in 1,263 publications. The same procedure as in the first literature search, that is, reading abstracts and sorting them into subcategories, was used. In the end, 541 articles were deemed to be relevant for the purpose of the study.

Table 2. Excluded keywords and subject areas.

Excluded keywords				Excluded subject areas
Emergency Service, Hospital	Infant	Aged	Patient Care	Veterinary
Emergency Ward	Health Care Personnel	Patient Monitoring	Clinical Trial	Economics, Econometrics and Finance
Major Clinical Study	Age Distribution	Child, Preschool	Health Care	Immunology and Microbiology
Hospital Emergency Service	Clinical Article	Preschool Child		Neuroscience

2.1.2 Research projects

Different searches were conducted to find research projects and groups. Search terms from Table 3 were used, with at least one term from each column, the operator AND was inserted between the columns of search terms. Search engines such as Google, Swedish university websites, research institutes and innovation platforms, were used. Some of the research projects were also identified through scientific publications and workshops (see section 2.1.4).

Table 3. Search terms used in a Boolean Google search.

Actor	Equipment	Activity
Rescue	Sensor*	Tracking
Fire ground	Body-worn system	Localization
First responders	Person* Protective equipment	Monitoring
Incident commander	Communication technologies	Alerting
Fire fighter	Safety equipment	Situation awareness
Emergency service		Indicating
		Development

2.1.3 Products and innovation

Details about the development of products available on the market were found through research projects/consortiums, in workshops with SMEs, and through specific searches on Google and innovation networks, using the same procedure as in section 2.1.2.

2.1.4 Workshops

Nine workshops with one to three participants at a time were held with researchers at the Swedish Defence Research Agency. A total of sixteen people participated, and the workshops lasted for around one hour each. The participants' competencies were in the areas of CBRN defense and security, radar systems, sensor informatics, robust telecommunications, command and control systems, and electro optical systems.

The idea of the workshops was two folded; one was to find new relevant research and the other was to ensure the quality of the literature searches that had already been performed.

During the days before the workshop, the participants received information about the study and the capability gaps. The workshop started with some background information and a description of the types of accidents where protection is needed (see 1.1.1). During the workshops, the participants' ongoing research was discussed, as well as if they knew of other related research, how established the research was and what their thoughts were of future research. Towards the end, the current map of areas was shown (Figure 2), to determine if the participants could add something that might be missing.

2.1.5 Attended fairs and symposiums

Some of the products were also identified during the fair *SKYDD* that was held 23-25th of October 2018 in Älvsjö, Sweden.

The National Symposium on Technology and Methodology for Security and Crisis Management (TAMSEC) was held at Linköping University on the 17th of October 2018. The symposium was organized by the research platform Security Link, and provided an overview of their research areas (Security-Link, 2018a). Security Link's member organizations are the Swedish Defence Research Agency, Linköping University, KTH Royal Institute of Technology and Chalmers University of Technology.

2.2 Analysis

The initial analysis was performed using an explorative approach. The purpose of the first search for scientific literature was to identify subcategories in the areas Protected, Connected and Fully aware (Figure 2). The identification process was only based on publication abstracts and the focus described in the publication. Research and development projects, products and the second scientific literature search were mapped according to the subcategories.

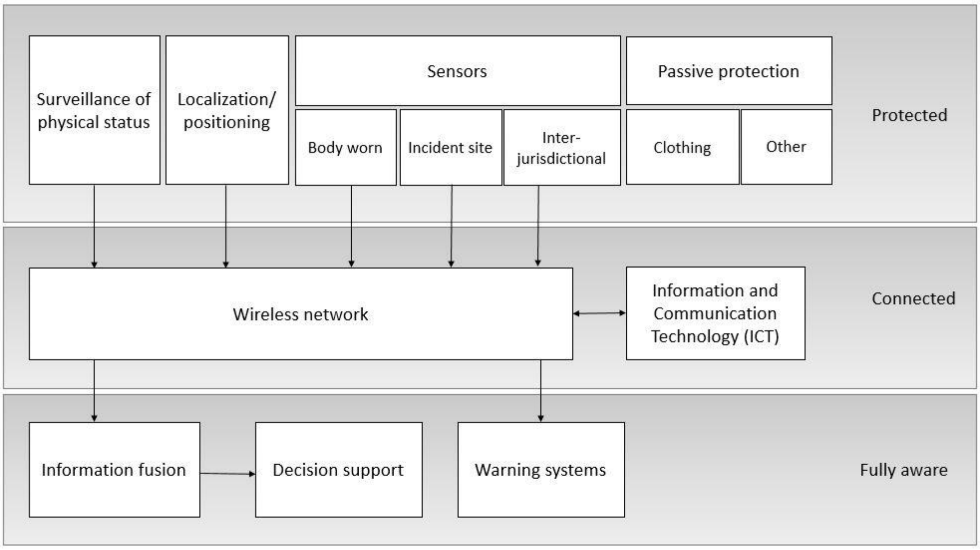

Figure 2. The map of the area created by the literature searches, online searches and workshops.

Specific searches and workshops were used to deepen the analysis in an iterative way. In the end of every workshop, the map of subcategories (Figure 2) was shown and discussed to see if any categories were missing. This contributed to new knowledge and, in some cases, new subcategories, a reorganization of these, and how they were related to each other.

As only abstracts and summaries from the publications and studies were read, the analysis in this report does not include a complete analysis of their relevance for the areas.

3. Results

During this knowledge review, different areas of research and development linked to the protection of first responders at the incident site were studied. Three areas were focused upon: Protected, Connected and Fully aware. The three capability gaps studied were the ability to: 1) in real time know the location of first responders and their proximity to risks and hazards, 2) in real-time detect, monitor, and analyze passive and active threats and hazards at incident scenes, and 3) rapidly identify hazardous agents and contaminants. A third purpose was to find research focusing on gender and differences in protection between men and women, and if there are requirements for adaptation.

Presentation of the results of the study is divided into four parts: Platforms and collaborations, Protected, Connected, and Fully aware. Each section starts with a brief summary, followed by examples of identified research and projects, and ends with examples of products/innovations.

The scientific literature was published in various ways, which indicates the wide range of the areas Protected, Connected and Fully aware. Identified literature included both conference papers and articles. Ten to fifty publications were found in the five most frequent journals: Applied Ergonomics, Ergonomics, Journal of Occupational and Environmental Hygiene, Proceedings of SPIE - The International Society for Optical Engineering, and various Institute of Electrical and Electronics Engineers (IEEE) journals and proceedings.

3.1 Platforms and collaborations

The different search methods resulted in a few general projects or platforms for research or innovation cooperation. It was shown that these kinds of collaborations are often related to all three areas. Several of the identified projects are part of the European Union (EU) framework programs (FP6, FP7 and Horizon 2020). Some of the projects within the frameworks are platforms, such as the project Smart@fire (Vlaamse Gewest, 2016), which aimed to find ways of developing innovations to increase safety for firefighters. Smart@fire has now entered pre-commercial procurement. The EU framework projects also gather various actors and create consortiums for further development.

The research platform SECURITY LINK, connects different areas in security research, is an example of the collaborations. In addition, the centers FOCUS (The FOI Centre for Advanced Sensors, Multisensors and Sensor Networks), CARER (The Center for Advanced Research in Emergency Response), KMC (The Centre for Teaching and Research in Disaster Medicine Traumatology), and Center for natural-disaster science at Uppsala University (Security Link, 2018b), are related to SECURITY LINK. Together, these organizations and centers produce a variety of research within the domains of wireless communication, sensors, information fusion, decision support, and risk analysis and ethics in crisis management. The EU FP7 project TWOBIAS (Two Stage Rapid Biological Surveillance and Alarm System for Airborne Pathogenic Threats) is an example of projects within SECURITY LINK .The project ended in 2013, with a “close-to-market” demonstrator of a stationary, rapid, reliable, vehicle-portable TWOBIAS, with extremely low false alarm rates (Forsvarets forskninginstitutt, 2016).

The platform FIRST (First responder of tomorrow) is another example of a platform for research and innovation in the area of firefighting. The aim is to link practitioners with researchers and companies. FIRST is a part of the Swedish research institute RISE (Research Institute of Sweden). There is a department for systematic product evaluation for first responder products (SPAR) that first responder organizations can turn to for help with evaluation when purchasing new equipment. An example of an ongoing project at FIRST is a study about the measures that are necessary in order to enable men and women to work in equal working conditions. (RISE, 2018)

The project Future of first Response is another example of collaborations. It is a collaboration between the Department of Homeland Security Science and Technology, Pacific Northwest National Laboratory, and Continuum. The aim is to bring together the first responder community, industry and government to define a mutual vision of tools, clothing and technology for first responders in the next 15 years (Pacific Northwest Laboratory, 2018).

WeRespond is an initiative from the USA. It is a community that aims to accelerate innovation for emergency responders (WeRespond, 2018). A similar example in Sweden is Winguard, which was started in 2016. The aim is to increase innovations within societal security and safety (Winguard, 2018). The network consists of innovation companies and prospective users (partners). The EVAM Transmit is an example of a product within Winguard that could enhance the ability to avoid accidents and incidents when responding to an accident. It is a digitalized V2V (vehicle to vehicle) communication system that allows real-time information (about approaching emergency vehicles or roadworks) to motorists in the direct vicinity (EVAM, 2018).

3.2 Protected

The majority of the research in this area concerns indoor-positioning and how the physical status of first responders can be tracked during a rescue operation. Both indoor positioning and surveillance of physical status are dependent on sensors. Sensors can be found in all active protection, but has also been allocated a section below. A few different areas, such as passive protection, physical status, positioning, and sensors are presented in further detail.

3.2.1 Passive protection

In this sense, passive protection means either equipment that you put on yourself or on the ground for protection against a known threat.

Characteristics of clothing

The research found in this area focuses on improving current equipment rather than developing new technologies. According to one of the Subject Matter Experts (SMEs), the development of protective equipment and smart textiles is driven by the industries' need for protection or by the needs of athletes. Nanomaterials are used to enhance clothing with relevant functions. Nomex is an example of nanomaterials in firefighting clothing. It was developed by the company DuPont, and is used, for example, as a barrier against particles in fire hoods (Viking, 2018).

The basic firefighter suit consists of thermal protective trousers, jacket, gloves and shoes that can resist high temperatures. Equipment such as breathing apparatuses (BA) and protective masks are also used. In a study by Tunell and Claesson (2017), the aim was to find common denominators for the respiratory protection of Swedish organization. By identifying the participants' different user needs and methodology at a CBRN incidents, they try to create and assess mutual base criteria's that are applicable for these organizations purposes.

Other types of protective clothes are chemical suits, or suits that protect against radioactive or biological contamination. This area of research entails the characteristics of protective clothes, as well as the actual protection of the material, and the ergonomic design. The characteristics of the clothes include testing on absorptivity of different materials (Collin et al, 2015), but also the thermal insulation behavior of multilayer clothing (Naeem, Mazari, & Havelka, 2017). In terms of ergonomics and gender, the research found relates to, for instance, how garments can be more appropriately designed for women, such as a better fit and sizing system (Hsiao, Whitestone, Kau, & Hildreth, 2015; Park & Langseth-Schmidt, 2016).

Some research found focused on a kind of textile that has a cooling effect, and that can be used underneath thermal protective clothes. These clothes are supposed to reduce the risk of heat stress and heat-related illness, which are common problems among firefighters. One solution is a new type of material (Sullivan et al, 2015), while another is a separate vest, which needs water to be activated (Deakin, Ennis-Thomas, & Armstrong, 2014). A similar type of equipment, a prototype of a lightweight cooling vest, was also developed in STAYCOOL (North West textiles network limited, 2013), an EU- funded research project. The status of the STAYCOOL system is not known.

The Swedish Defense Research Agency (FOI) conducted a research project about physical protection and decontamination for the Swedish Armed Forces. The project aimed to find methods on how to validate different PPE and different chemical subjects. In addition, the project investigated protection versus the ability to perform other duties (Tunell et al, 2011).

The main part of the research found focused on thermal protective clothes rather than on other protective clothes, such as chemical suits. Research found on chemical suits was more about testing how easy they are to use while performing rescue operations (Kim, Kim, Shin, & Haam, 2016). Workshops with SMEs revealed that equipment, such as chemical suits and protection masks, is mainly developed by companies. Researchers' tasks more likely include evaluation of the equipment in various tests, such as how suitable the equipment is for rescue performance.

Passive protection on site

In addition to clothing, there are other kinds of passive protection. A common incident site is on the road following a car accident. If the traffic is still running, protection is needed. Protection in this case could be signs with lights that make drivers pay attention to the incident site. This kind of equipment is already available on the market (TopRight Nordic AB, 2017). Another example of passive protection for working on roads that is available on the market, is special vehicles that protect both the first responders and the drivers (Sbff, 2016), or the EVAM system mentioned above (see 3.1.).

3.2.2 Surveillance of physical status

A major part of the research in the area of protection focuses on sensors that monitor physical status, such as temperature, pulse and oxygen level, and that can be carried by the individual firefighter. The background to this field is the heat stress that occurs in firefighting. It affects firefighters and is one explanation for fatalities. The technology is built into textiles (smart textiles), see WASP below, and could easily be worn beneath thermal protective clothes. Smart textiles are often developed with nanotechnology. This makes it possible to include elements with electronic and optical fibers, sensor yarns, transducers between electrical and optical signals, sensor stripes and functionalized fabrics.

The European FP7 project I-protect has developed an advanced PPE-system that ensures active protection and information support for personnel operating in high risk and complex environments in firefighting, chemical and mining rescue operations. The system can monitor both the physical status of the individual and the environment (Central Institute for Labour Protection-National Research Institute, 2014). The system has been tested and validated, but no further information about the current status of the prototype could be found.

When it comes to the monitoring of physical status, research has resulted in final products that are ready to be used. One example of a research project that is now an available product on the market is the Wearable Advanced Sensor Platform (WASP), developed in the USA. It is a bodyworn system with sensors in the fabrics, which integrates physiological and location monitoring into a single system that collects, transmits and displays integrated user data in real time to an incident commander or EOC (Globe, 2017).

A similar solution was developed as a part of the European innovation project Smart@fire (Vlaamse Gewest, 2016). The Texport consortium was founded within the project Smart@fire and started to develop a PPE solution with integrated sensors for surveillance of physical status, position monitoring and gas detection (Texport consortium, 2016).

3.2.3 Localization and positioning

Knowing where personnel is located is important for both efficiency and security during the rescue operation. Information about position is required both by the incident commander but also between first responders (Ferreira, Fernandes, Catarino & Monteiro, 2017; Albrecht & Heide, 2018). The focus of the identified research in this area is mainly on systems for indoor positioning, although a small proportion is about outdoors positioning.

Positioning can be done with different technologies, such as sensors or algorithms. An example of techniques used is Pedestrian Dead Reckoning (PDR), which uses shoe-mounted sensors that calculate where a person should be, depending on their last known location (Syed, Brown, Garrity, & Mackinnon, 2015). Other examples are accelerometers, gyroscopes and pressure sensors that send information to the algorithms (Scheurer, Tedesco, Brown, & O'Flynn, 2017).

The Swedish project TOR (Tactical lOcatoR) has developed equipment for indoor positioning, using a foot mounted device from the earlier project OpenShoe and open source networks. The equipment was developed during 2013-2016 by researchers at the Royal Technical Institute (KTH) and was tested in real cases during BA rescue situations (Nilsson, Zachariah, Skog & Händel, 2013). The open source code from OpenShoe has been commercialized into a product for indoor positioning (Inertial Elements, 2018).

Another technique is Simultaneous localization and mapping (SLAM), which has been used in various research projects (Albrecht & Heide, 2018; Kosyanchuk, Smirnov, & Panyov, 2015). The developed systems can locate the carrier and draw a map of the surroundings. One example of a research project is Chameleon, where technology developed for the military were also tested on BA operators (Emilsson, & Rydell, 2014).

Ultra Wide Band (UWB) is a technology that is small and lightweight, and that can be carried by first responders. The tag allows precise indoor localization and identification of the user (Zetik & Del Galdo, 2017). This method is also used in a European project, EUROPCOM, which uses radio equipment for localization and positioning (Harmer et al, 2008).

It is not clear whether any of the prototypes from the research projects mentioned above have been developed into products, but there are other products for indoor positioning on the market. Examples include the indoor positioning system *TRX-systems* (TRX-systems, 2018), and SRT. The latter is a personal alarm used for localization in- and outdoors, which also has a “man down” function that sends an alarm if the carrier is in a laying position for a sustained period of time (Scandinavian Radio Technology, 2018). For outdoor positioning there is a solution that was developed in 2017 by the innovation company WILDA spårning AB (Wilda spårning AB, 2018).

3.2.1 Sensors

Using a sensor can have different purposes and there is a wide range of sensors. For example, sensors can be used to detect emissions and measure dispersions, chemicals or explosives in the air, on the ground, or in water. Sensors could also be surveilling cameras with algorithms that detect abnormalities in crowds of people. An aspect of sensors are their locations. They could be body worn, like in the area of surveillance of physical status mentioned above, or they could be positioned at different locations on the incident site. They can be mobile or static, or they can be inter-jurisdictional and already in place in the community, e.g., according to the concept of smart cities. Research and development on sensors is detailed in groups below, based on their location.

Body worn sensors

Body worn sensors are sensors that can be carried by a person. The sensors can either sense the physical status of the carrier (described above), or monitor environmental parameters and detect threats in the surroundings. The devices are either handheld or mounted on the carrier. IntelTex (Nanocyl S.A., 2010) was an EU FP 6 project that integrated sensors in textiles for detection of chemicals. There is no information on the current status of the developed products in IntelTEX. Various research and development projects also include displays for the person carrying the device. The displays are either carried and connected to the device or head up displays (HUD).

There are several products available on the market for detection of chemicals. For example, there is a multispectral device developed by Serstech (2018), which maps the sensor data to a database of chemicals. According to one of the SMEs, devices that combine different sensor techniques and that can analyze chemicals in an instant are lacking in the area of detection.

Incident site sensors

Body worn sensors are a part of incident site sensors. However, in this report they are described separately. The incident site sensors that are used are both static and mobile. However, the research on static sensors is more established then that on mobile ones (Hutchinson, Oh, & Chen, 2017). As for mobile sensors, the ongoing research also focuses on the carriers, e.g., vehicles, UAVs and robots. The advantage of an UAV is that it can be sent to the incident site in advance, create a picture of it and detect certain risks. The incident commander could also use the UAV to monitor the incident site in parallel with the rescue work. Robots are also used as carriers and sent into buildings to create a picture of the inside without having to risk the lives of the personnel. This could be done either in the beginning of the rescue operation or in parallel with the UAV/robot (Li, Li, & Xu, 2015; Elgebali et al, 2017). On the private market, both UAVs and robots have been developed for the purpose of carrying sensors for managing the incident site. Examples of this include the firerobot FUMO (AB Realisator Robotics, 2018), IdentifAI, a combination of a UAV and picture analysis (Globhe, 2018), and Airee, a UAV with sensors (Airee, 2017).

Examples of research projects on sensor technology include the EU-funded project OPTIX (Optical Technologies for the Identification of Explosives). The project has now ended, but it aimed at providing a new tool for detection of explosives, such as Improvised Explosive Devices (IEDs), from a safe distance (Zachhuber, Gasser, Chrysostom, & Lendl, 2011).

Radar is a kind of sensor that, for example, is used to “look around corners” and to locate victims without having to enter a hazardous area (Zetik, Eschrich, Jovanoska, & Thoma, 2015). Radar can also be used for mapping the incident site and monitor risks such as landslides or building collapse. The technique that is often used for 3D mapping is called LIDAR. It is used, for example, in the self-driving car industry. Radar is one of the techniques that will be used in a recently started project funded by Vinnova, where sensors carried by a UAV are used to map the incident site and detect hazardous areas on site (Vinnova, 2018). Human Detection System is a Swedish product developed for detection of moving objects behind walls or other obstacles (Cinside, 2018).

Sensors can also react to sounds such as a shoot array. Today, these kinds of sensors are commonly used in the military to determine the direction of gunfire (Raytheon, 2018). A situation where this could be useful for first responders is on the incident site of a terror attack. If there are terrorists left on site who start to shoot at first responders, they need to know the direction for taking cover.

Inter-jurisdictional sensors

The term *Smart Cities* refers to technology built into the urban society. It collects, aggregates and analyzes real-time data (Palmieri, Ficco, Pardi, & Castiglione, 2016). In most urban areas, several sensors, cameras and networks are already in use in buildings, other infrastructure and outdoors. According to the concept Smart cities, research focuses on new systems for crisis and rescue operations, as well as research about how to adapt and use existing systems. The EU-funded research project P5 (Privacy Preserving Perimeter Protection Project) presented a system as an example on how different sensors can be used to detect threats to critical infrastructure. This system comprises both active and passive sensors, such as radar, visual and thermal sensors (FOI, 2017). The project has now ended and no new information about the system is available.

A solution on how to use an existing sensor system was tested in a user case in the EU-funded project SAFECITY. A sensor network in a railway tunnel and on a train, monitored passengers and the air quality, and forwarded the information to functions in the rescue organization, both on site and to the EOC (Granlund et al, 2011).

Integrating sensors in buildings to achieve comfort, safety and energy efficiency is growing more common. Systems such as Building Information Modelling (BIM) is a common approach to creating a digital collection of a building's data during its life cycle. In some cases, this includes disaster prevention (Wang et al, 2014). The EU-funded project SCUBA looked at how to gather information in a building with regard to the people living there, the location of the fire, evacuation points, etc. (Mc Gibney et al, 2013).

3.3 Connected

The focus of research in the area Connected is primarily on active protection/equipment that can be portable or part of clothing. The sensor data about, e.g., physical status is automatically sent to other systems.

Below are examples of several research projects about how data can be transferred from the inside of buildings to the personnel outside. There are examples, such as local Wi Fi or “bread crumbles”, that act as small routers and enable tracking of a BA-operative’s path.

3.3.1 Wireless networks

Surveillance and positioning requires some sort of network that can send and receive information. Within the concept of Smart Cities, existing networks in the community are considered. However, these are not enough and there is also a risk that these systems will be damaged in case of a crisis. Several research projects focus on how to build local networks that can facilitate communication and localization at the incident site, see examples below. In addition, public protection and disaster relief (PPDR) organizations usually have different kinds of wireless communication technology, which in turn can create difficulties when cooperating due to problems with information sharing.

In an extensive survey of current and future applications and challenges for wireless communication, Baldini, Karanasios, Allen & Vergari (2014) summarized how Public Safety organizations can utilize this technology. In their survey they investigated a variety of things, such as functions (law enforcement, firefighting, etc.), scenarios (urban or rural environment, borders, etc.), different features of communication services (voice, data, messaging, push-to-talk and security services), requirements, and comparisons between commercial and military domains.

In the project RESCUE, the aim was to help first responders communicate even if commonly used infrastructure was damaged. This could be achieved by deployment of broadband communication infrastructure in the event of a disaster (Gilat Satellite Networks Ltd., 2013). The current status of the project is unknown.

SAVE ME (System and actions for vehicles and transportation hubs to support disaster mitigation and evacuation), was an EU-funded project in which a system that can detect and guide evacuation in case of a disaster event in public transport terminals/vehicles and critical infrastructure (tunnels/bridges) was developed. The idea was to support quick and optimal mass evacuation guidance, save the lives of the public and minimize the risks for first responders. (University of Newcastle upon Tyne, 2012; Coconea et al., 2014)

Other studies on emergencies in tunnels have looked into wireless networks when responding to a fire-in-tunnel incident (Erd, Schaeffer, Kostic & Reindl, 2016). May, Mitchel & Piper (2014) e used reconfigurable wireless networks with good results concerning effectiveness, efficiency and confidence of first responders.

Other technologies for wireless communication that can overcome cooperation problems between PPDR organizations are Software-defined Radio (SDR) and Software communication architecture (SCA) (Baldini, Sturman, Dalode, Kropp & Sacchi, 2014). Decentralized ubiquitous networking is another technology that can be used for PPDR organizations (Panaousis, Ramrekha, Politis, & Millar, 2012).

FeuerWhere (Tracking Fire Fighters) was a German project with the aim to develop wireless, self-configuring sensor networks that could monitor the firefighters' location and physical status, as well as environmental parameters (Baar, 2010; Piotrowski, Sojka & Langendoerfer, 2010).

Wireless Sensor Networks (WSN) is another technology that can be applied to many different areas. It has been used by the military to surveil the battlefield and create situational awareness (Hua, Li & Yan, 2011), but could probably be useful for first responders too. An example of this is by combining it with PAN (Personal Area Network) architecture (Eliasson, Zhong & Delsing, 2010).

Combining wireless body area networks (BAN) with smartphones is one way of visualizing measurements of physical status. The safety and security of the information needs to be considered when using this technology (Wagner, Kuck, Cabrera, Enoksson & Sieber, 2012).

Using public safety network systems incorporating laptops, surveillance systems, hand-held computers and cell phones is not trouble free. Several things need to be considered, e.g., security risks (McGee, Coutiére & Palamara, 2012), and the network's ability to transmit different types of data (Davison et al. 2010).

One commercial product found in the field of wireless networks is Broadsword Spine, a network that delivers power and data connectivity and that is built directly into clothing (BAE Systems, 2018).

3.3.2 Information and Communication Technology (ICT)

The Mobile Object Bus Interaction (MOBI) research and development project was a collaboration between Laurea University in Finland, the Finnish police and industrial partners. The goal was to minimize the number of systems in emergency vehicles and create a common ICT infrastructure for all emergency vehicles. The ICT-system was divided into four layers (vehicle infrastructure and power management, communication, service platform and common service, and actor-specific), with a standardized interface between the layers (Tikanmäki, Rajamäki, Pirinen (Eds.), 2014; Rajamäki, 2013). A demonstration vehicle was used for test and research, but no further information could be found after the publications in 2014.

Shih, Chen and Yeh (2014) developed a service recovery framework for a messaging service for disaster management. The reason was that they perceived that the messaging services for disaster alerts often were developed on existing messaging services with an underlying network that was not designed to be reliable during a disaster. FirstNet is a currently used network for public safety communication. This communication network is based on commercial standards and was created to give public safety organizations updated communication tools (First Responder Network Authority, 2018).

Using geotagged photographs taken at the incident site (either by citizens or by first responders), and incorporating these in the European Copernicus

Emergency Management Service could produce near real-time extent maps. This was done in a project by Rossi, Heyi & Scullino (2017), where a mobile application was created, that with the help of cloud web services could collect geolocalized data and enable a crowdsourcing approach during a scenario such as a natural hazard event.

EULER (EUropean software defined radio for WireLEss in joint secuRity operations), was an EU FP7 project. The project was about wireless systems communication integration and software defined radio, with the aim to enhance interoperability (Baldini et al., 2011).

3.4 Fully aware

The area Fully aware is a combination of the areas Protected and Connected, where added value has been created, often by a decision support system.

The great mass of research found within the area of Fully aware is concentrated on GIS-based (Geographic Information System) command and control systems, where risks, units and other items can be plotted and marked on a map and shown both on the incident site and in the Emergency operations centers (EOC). The area also entails research on how to enhance situational awareness by information fusion of social media and the use of internet of things (IoT). Warning systems is an area within Fully aware that was covered by the workshops, but not by the initial research and development searches.

3.4.1 Information fusion

The category information fusion concerns the compilation of information from several sensors and other sources. Social media and crowdsourcing are examples of information gathering from the public.

Social media has been used to gather information in several studies, either by using human-as-sensors (Boddhu, Dave, McCartney, West, & Williams, 2013), to create maps (Aulov, Price, & Halem, 2014), or to increase information in the common operating picture (Bareiss, Griss, Rosenberg, & Zhang, 2011). PhotoNet, an application based on these ideas, was a picture delivery service for camera sensor networks, where survivors and first responders could send photos to an EOC (Uddin et al., 2011; Wang et al., 2011,). Crowdsourcing (where annotators has analyzed data) has been used in a study with video surveillance to enable analysis of real-time data for first responders (Gadgil, Tahboub, Kirsh, & Delp, 2014). Advanced Forest Fire Fighting (AF3) was an EU FP7 research project that focused on developing innovative technology to integrate new and existing systems (Thomopoulos et al., 2016). Among many things, crowdsourcing was used to achieve higher reliability and less false alarm rates when using information from public information channels such as social media.

Chen, Lin & Wang (2013) proposed a rescue service architecture that was sensor-assisted and designed to provide personalized situational awareness. GIS (Geographic Information System) is an application area that supports situational awareness through data management, planning and analysis (Perdikaris, 2011). Another technique used to enable situational awareness is

RFID (Radio Frequency Identification). Chen et al. (2010) created a system for first responders for efficient gathering, storing and sharing of building assessment information by RFID.

Internet of Things (IoT) is another area of technology that can be used to enhance situational awareness. In an online survey, Schroeder, Manz, Amaya, McMakin, & Bays (2018) asked 250 U.S. first responders how they perceived parameters such as effectiveness, security and reliability with regard to IoT technology. Several studies on the benefit of IoT for first responders have been performed, e.g., to assess how IoT can facilitate emergency response operations (Yang, Yang, & Plotnick, 2013). An IoT-based framework has also been used to monitor environmental parameters to alert to thresholds being exceeded. The idea is to guide rescuers to the right place to avoid the waste of resources by being at the wrong place, i.e., no victims or little damage (Mongiello et al. 2017; Mongiello et al. 2018).

3.4.2 Decision support systems

The category Decision support systems focuses on research and development of how data and information is presented to enhance situational awareness and facilitate decision-making. Examples of this might be visualization of dangerous areas, or compilation of the physical status or location of staff.

The project ARTEMIS CAMMI (Cognitive Adaptive Man Machine Interface) focused on a joint-cognitive system to enhance operators' performance in a demanding situation. One application was an interface for firefighter commanders (De Graaf, Varkevisser, Kempen, & Jourden, 2011).

Within the AF3 (Advanced Forest Fire Fighting) project, the tool OCULUS Fire was developed. This command and control system was a monitoring, GIS and Knowledge Extraction System and Visualization tool (Thomopoulos et al., 2016). The project ended in 2017 and there is no current information about the command and control system.

Much of the research concerning C4ISR (Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance) lies within the military domain (Müller et al. 2017), but could possibly be used in the domain of first responders. Around the world, there are several ongoing soldier modernization programs. These systems are designed for military use, but many of the applications are useful for first responders. One example of such a system is the Canadian ISSP (Integrated Soldier System Project). The aim is to enhance situational awareness by enabling the soldiers to stay connected with their team, provide navigational information and improve command and control (National Defence and the Canadian Armed Forces, 2018). Another military study tried to improve situational awareness by matching the mental models and information needs of the commanders, using the decision support system (Streefkerk, Smets, Varkevisser, & Mastrigt, 2014). In studies on Swedish military commanders, the tool The Impact Matrix, which has previously been used in business for risk management, was used. In these studies, the tool was used to enhance the commanders' situation awareness by presenting probabilities of various future events (Nilsson, van Laere, Ziemke, Berggren, Kylesten, 2008; Svenson, Berg, Horling, Malm, & Martenson, 2007).

Some research studies have incorporated technology such as GPS, GIS and GSM in their system for decision-making (Kamoun, Werghi, & Blushi, 2010). Other researchers have proposed conceptual models or prototypes of platforms, which integrate information from several sensors such as UAVs, body sensors and cameras (Suciu et al., 2018; Mohsin, Steinhäusler, Madl, & Kiefel, 2016). Foresti, Farinosi & Vernier (2015) have taken it one step further and presented an Advanced System for Emergency Management (ASyEM). In this system, sensor data from smart sensors in the environment is processed and integrated with user-generated data from socio-mobile applications, such as Twitter.

The THEMIS (disTributed Holistic Emergency Management Intelligent System) is an ongoing project that supports real-time disaster management for both decision-makers and responders by a georeferenced common picture built on information from users, sensors and crowdsourcing (Nunes, Lucas, Simões-Marques, & Correia, 2017)

There are several studies that focus on visualization. One of them concerns HiGRND (Hierarchical Grid Referenced Normalized Display), a visualization tool for first responders that can track and locate first responders and also turn 2D blueprints into 3D objects (Woodley, Petrov, & Meisinger, 2010). Another system creates a 3D model of a building in real-time for an operational commander, using data from a mobile system carried by the first responder (Schönauer, Vonach, Gerstweiler, & Kaufmann, 2013).

In buildings with network infrastructure, there could be built-in Fire Alarm Control Panels (FACP) that can facilitate evacuation. After some functionality adaptations, these systems could also be used by firefighters during a fire. If the FACP is equipped with Wi-Fi and LTE (Long Term Evolution, 4G), robots that scout the building and stream live video could be connected with the FACP and send real-time information to the incident commander (Elgebali et al., 2017).

3.4.3 Warning system

Warning systems were discussed with SMEs during the workshops. The discussions dealt with how warnings should be presented and for whom, i.e., the actual first responder, the whole team, the incident commander, or the EOC. One idea that was discussed was wearing material that changes color when contaminated, but no research on whether this has been tested could be found.

In the original searches, no specific results were found regarding how to give first responders a warning if a threat is closing in. Special searches were conducted after the workshops to find relevant research and development. Warnings could either be a talking message, a signal, a visualization or a tactile cue. For example, in the U.S., there is a standard for using Personal Alert Safety Systems (PASS devices). This is a device that gives a signal if a firefighter is incapacitated on the fire ground (FEMA, 2012). Similar Swedish products include the SRT Personal Alarms that has a “man down” function, see section 3.1.3 (Scandinavian Radio Technology, 2018). A research project at the University of Sheffield has developed a tactile helmet that makes the wearer aware of the surroundings by sending sensor signals when approaching an obstacle (Bertram, Evans, Javaid, Stafford & Prescott, 2013). The helmet could help firefighters obtain better vision without using their eyes. The tactile technique could also be used for warnings. It is not clear whether this technique is in operational use.

4. Discussion

The main purpose of this knowledge review was to find research and development projects as well as available products in the areas Protected, Connected and Fully aware. The searches that were conducted revealed a higher proportion of research related to the area Protected, which mainly contains technical solutions for first responders. The research in the areas Connected and Fully aware is not as closely linked to first responders as the area Protected. Some of the studies tried to broaden the perspective and include the areas Connected and Fully aware by developing a solution that, for example, incorporates the whole chain of events from a sensor, through a wireless network and ending up as decision support for the incident commander. However, the objective of these studies was rarely defined as a whole solution, but focused on one of the areas.

A second purpose of this knowledge review was to identify research and development projects focusing on three capability gaps. These were the ability to: 1) in real time know the location of first responders and their proximity to risks and hazards, 2) in real-time detect, monitor, and analyze passive and active threats and hazards at incident scenes, and 3) rapidly identify hazardous agents and contaminants. The findings related to the capability gaps were mainly found in the area Protected.

Furthermore, research focusing on gender was of specific interest. Only a few of the studies included in the results addressed the question about gender differences, and research where gender was considered mainly concerned protective clothes and sizing. What was noticed in other studies was that in tests conducted with firefighters, the participants were mainly male.

The search terms that were used for finding relevant research were identified from the specification of this study (FOI-2018-954:5/MSB 2018-05091) and the different accident scenarios (see chapter 1.1.1). This report is mainly based on reading abstracts and project summaries, although a few studies were reviewed in more detail. Due to the chosen methods, it is possible that relevant concepts and research areas are missing in this study. Even if there are some concepts that should have been included, the various ways of finding information have probably decreased that risk. The research that might have been overlooked is probably to be found on the outskirts of the identified research areas.

4.1 Discussion of results

In the research projects, the developed equipment mainly consisted of prototypes, demonstrating how the technology can be used. Many of the projects found and most EU framework projects reported their results within the project period, but then all information about the developed product ceased. There is no knowing if the prototype was commercialized into a product or if the prototype was unsuccessful. In this report, only a few commercial products were found and presented. The reason could be that a lot of the technology is new and that private development projects are not as open or as widely reported on as research projects. The searches conducted were also specific in that they were aimed to find projects and products within the domain of first responders, using search terms such as “firefighter”, “incident site” and “fire ground”. This could also have led to overlooking some results, as products and prototypes that are developed for other domains could be used by first responders. Several of the SMEs that took part in the workshops had a good knowledge of the military industry, which is one domain for finding relevant products. Other domains identified in workshops as possible candidates for developing equipment suitable for first responders are the sports industry, where new materials and smart textiles are developed, and industries that use personal protective equipment.

The research mainly originated from the USA or Europe. The needs for new technology and methods varied between different countries, which could be explained by different numbers of line of duty casualties. The different needs could also depend on different working procedures and standard operating procedures (SOP). In addition, the infrastructure and climate differed between countries. This affects both the risks and the protection already built into the infrastructure, such as sensors, passive protection, etc.

In several of the conducted workshops, discussions were held regarding what information should be presented and to which function, on the incident site or EOC. Many of the research projects focused on technical devices for protection rather than methods. In particular, research on how humans and technology can interact was lacking. Methods for using technology are mainly developed through best practises and through lessons learned after introducing new technology. In some rare cases, researchers have validated the methods. There is a risk that too many solutions without integration will lead to information overload, which in turn could have a negative impact on both efficiency and security.

Several of the research and development projects were vague about the problem or need addressed by the technology, and how the technology might be the solution and not another distraction. In some cases, firefighters have gone missing in fires, which motivates equipment for positioning. However, the question whether this kind of equipment would have saved lives is rarely answered, particularly as there is not a clear method for how technology can enhance security and safety. Different kinds of trauma, for example, accidents when responding to an emergency or collapsing buildings during a fire, are areas that were not discussed in the identified research and development projects. The same goes for problems at traffic incidents, where casualties are more common, e.g., in Sweden.

4.2 Conclusions

The overall purpose with this knowledge review was to identify what research has been conducted in the areas of Protected, Connected and Fully aware for first responders. Below, the overall conclusions (without ranking) that can be drawn from the identified research and development are listed.

- The whole area of research and development concerning protection for first responders is very diverse. There were fewer research groups found than anticipated, and much of the product development seems to be driven by the private market, and therefore difficult to find through conventional searches. What stands out are the EU-framework projects; these projects connect the academic research domain with private companies. However, it is hard to find information whether the prototypes have been further developed.
    - A deeper review of what happened to prototypes from EU projects would be useful. This could be accomplished by contacting coordinators from relevant EU projects.
- Based on the method of this study, some research and development might have been overlooked or simply does not exist. We propose more searches on research within the following areas;
    - How to discover risks for building collapse.
    - Research on chemical suits and instruments for detecting chemical hazards.
    - How to legislate on the usage of sensors in smart cities and between different actors for important information sharing.
    - How to use technology built into infrastructure, both active and passive, and how to develop relevant methods so that the equipment is actually used.
    - How research and development can be generalized from other domains to first responders.

4.3 Future recommendations

We propose the following recommendations for future studies within the area:

- Future research should have a close connection to the requirements and needs of first responders, both for preventing line of duty deaths and for managing other security and safety requirements.
- New technology should a focus on usability. For example, sensors have to work by themselves, the devices/equipment need to be smaller, and user tests need to be conducted during the whole development process.
- Sensor equipment should be more self-analytic and the information should be shown to the user in real-time instead of being analyzed by experts off-site.

- Further searches about research, development and innovations to find information on subjects identified as missing in the present study, by:
    - Using other databases for scientific research.
    - Carrying out more in-depth searches in specific areas.

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