National Defence University

Series 1: Research Publications No. 19

A Common Operating Picture for Dismounted Operations and Situations Room Environments

Jussi Timonen

JUSSI TIMONEN

A COMMON OPERATING PICTURE FOR DISMOUNTED OPERATIONS AND SITUATION ROOM ENVIRONMENTS

ACADEMIC DISSERTATION

To be presented, with the permission of the Research Council of National Defence University, for public criticism for the degree of Doctor of Military Sciences in auditorium Itälinnake at the National Defence University, Santahamina, Helsinki, on 9.3.2018 at 12 a clock.

NATIONAL DEFENCE UNIVERSITY
HELSINKI 2018

MAANPUOLUSTUSKORKEAKOULU
JULKAISUSARJA 1: TUTKIMUKSIA NRO 19

NATIONAL DEFENCE UNIVERSITY
SERIES 1: RESEARCH PUBLICATIONS NO. 19

A COMMON OPERATING PICTURE FOR DISMOUNTED OPERATIONS AND SITUATION ROOM ENVIRONMENTS

JUSSI TIMONEN

NATIONAL DEFENCE UNIVERSITY
HELSINKI 2018

Timonen, Jussi: *A Common Operating Picture for Dismounted Operations and Situation Room Environments*
Maanpuolustuskorkeakoulu
Julkaisusarja 1: Tutkimuksia nro 19
Väitöskirja /
National Defence University
Series 1: Research Publications No. 19
Doctoral dissertation

Author:	MSc. (eng.), Captain (eng.) Jussi Timonen
Supervising professor:	Professor Jouko Vankka National Defence University, Finland Department of Military Technology
Preliminary examiners:	Professor Marko Nieminen Aalto University, School of Science Department of Computer Science
	Adjunct professor Kari Kallinen The Finnish Defence Research Agency Human Performance Division
Official opponents:	Professor, Colonel Mika Hyytiäinen National Defence University, Finland Department of Warfare
	Adjunct professor Kari Kallinen The Finnish Defence Research Agency Human Performance Division

Recent publications in PDF format: *http://www.doria.fi/handle/10024/73990*

ISBN 978-951-25-2994-0 (pbk.)
ISBN 978-951-25-2995-7 (PDF)
ISSN 2342-9992 (print)
ISSN 2343-0001 (web)

Maanpuolustuskorkeakoulu
National Defence University

Juvenes Print
Tampere 2018

ABSTRACT

This dissertation focuses on exploring the technical possibilities for supporting situation awareness for the users in different environments. Modern society is highly dependent on knowledge, which supports vastly complex infrastructures and operations. As the size and complexity of critical infrastructure (CI) is increasing, understanding the actual situation becomes challenging. For these reasons, the need for exploring the measures for delivering the right information to the right user at the right time becomes crucial.

The two key environments explored are the monitoring room environment for protecting critical infrastructure and the operations of dismounted military forces in an urban area. The research is based on two implemented proof-of-concept environments for these scenarios. In the field of urban area warfare, the Mobile Urban Area Situational Awareness System (MUSAS) is used to evaluate the requirements and usage of dismounted troops. The aspect of critical infrastructure is studied using the created Situational Awareness of Critical Infrastructure and Networks System (SACIN). The ultimate goal is to create an accurate and insightful common operating picture (COP), which actually supports the user in making decisions and understanding the events. The approach is technical and focuses on the ways of creating and distributing the COP. In addition, the study includes methods for measuring the situation awareness of the operators using the systems.

The main contributions of the dissertation are the created concepts, architectures, and implementation of the proof-of-concept systems. These contributions are supplemented with the results of measuring the situation awareness (SA) of the end users. A service-based approach offers a means to spread the services to the entire network, starting from the strategic level and reaching the end users. By these means, efficient and human-friendly COPs for different environments can be built.

Keywords: Common Operating Picture, Situation Awareness, Services, Critical Infrastructure, Dismounted Troops, Monitor Room Environment

ACKNOWLEDGEMENTS

The process of making this dissertation has been a great journey. In this context, I have had the pleasure of meeting many researchers who have offered me insights from their own research and commented on my perspectives. Probably the single most rewarding thing in the whole process has been the possibility to meet and discuss with intelligent individuals from all across the globe.

Firstly, I would like to thank my supervisor professor Jouko Vankka for the guidance and opinions among the way. I would also like to thank the pre-examiners, professor Marko Nieminen and adjunct professor Kari Kallinen for the accurate and valuable comments, which helped me to improve the work.

I want to express my gratitude to the organizations in the Finnish Defence Forces, which have supported me over the years. The FDF has offered a great deal of support in terms of resources, knowledge, and understanding. I started the dissertation process while working in the National Defence University and finished it while working at the Finnish Defence Research Agency. I would also like to thank the Finnish C5 agency for supporting me in making this dissertation. The environment could not have been better or more nourishing for this kind of project. Thank you for the many conversations and help!

During my work, I had the pleasure of participating in the work of two great research groups. This time formed the core substance of my work and provided the understanding of what academic research in technical field actually is. Thank you all in the WISM II and DiSCI projects!

Lastly but not least I would like to thank my wife Oona and daughters Aino and Emma for their support. I have been forced to spend a big part of my time on this project over the years and have not always been able to focus on you. Thank you for your understanding and enabling me to work.

As expected, making the dissertation is a constant learning process where the candidate has the aim of developing into a researcher. My journey lasted for approximately five years. Now it is easy to recognize that the outcome, this dissertation, is not the main contribution; it is the journey of making one.

Mynämäki, 21.1.2018

Jussi Timonen

PUBLICATIONS OF THE DISSERTATION

I. Saarelainen, T. and Timonen, J. Tactical management in near real-time systems. Paper presented at the *IEEE First International Multi-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support (CogSIMA)*, Miami Beach, Florida, doi: 10.1109/COGSIMA.2011.5753452, 2011.

II. Timonen, J. Distributed Information System for Tactical Network. Paper presented at the *3rd Workshop on Wireless Communication and Applications (WoWCA),* Vaasa, Finland, 2012.

III. Timonen, J. and Vankka, J. Enhancing situational awareness by means of visualization and information integration of sensor networks. Paper presented at the *Proc. SPIE 8756, Multisensor, Multisource Information Fusion: Architectures, Algorithms, and Applications,* Baltimore, Maryland, USA, doi:10.1117/12.2017686, 2013.

IV. Bjorkbom, M., Timonen, J., Yigitler, H., Kaltiokallio, O., Vallet Garcia, J. M., Myrsky, M., Saarinen, J., Korkalainen, M., Cuhac, C., Jäntti, R., Virrankoski, R., Vankka, J., and Koivo, H. N. Localization Services for Online Common Operational Picture and Situation Awareness. *IEEE Access* vol 1, pp. 742–757, doi:10.1109/ACCESS.2013.2287302, 2013.

V. Timonen, J., Lääperi, L., Rummukainen, L., Puuska, S., and Vankka, J. Situational awareness and information collection from critical infrastructure. Paper presented at the *6th International Conference on Cyber Conflict (CyCon),* Tallinn, Estonia, pp. 157–173, doi: 10.1109/CYCON.2014.6916401, 2014.

VI. Rummukainen, L., Oksama, L., Timonen, J., and Vankka, J. Situation awareness requirements for a critical infrastructure monitoring operator. Paper presented at the *IEEE International Symposium on Technologies for Homeland Security (HST),* Boston, USA, doi: 10.1109/THS.2015.7225326, 2015.

VII. Rummukainen, L., Oksama, L., Timonen, J., and Vankka, J. Visualizing common operating picture of critical infrastructure. Paper presented at the *SPIE Sensing Technology+ Applications. Vol. 9122, Next-Generation Analyst II,* doi:10.1117/12.2050231, 2014.

VIII. Puuska, S., Rummukainen, L., Timonen, J., Lääperi, L., Klemetti, M., Oksama, L., and Vankka, J. Nationwide critical infrastructure monitoring using a common operating picture framework. *International Journal of Critical Infrastructure Protection,* Available online 6 December 2017, ISSN 1874-5482, https://doi.org/10.1016/j.ijcip.2017.11.005, 2017. (In press, Accepted Manuscript)

IX. Timonen, J. Improving Situational Awareness of Cyber Physical Systems based on Operator's Goals. Paper presented at the *International Conference on Cyber Situational Awareness, Data Analytics and Assessment (CyberSA)*, London, United Kingdom, pp. 1–6, doi: 10.1109/CyberSA.2015.7166121, 2015.

The author of this thesis is the sole author of the papers [II], [IX], and [III], to which Professor Jouko Vankka provided invaluable insights and comments. In [I], the author was responsible for software-related topics and implementation. The author is the main author in [V] and took part in writing [IV], [VI], [VII], and [VIII].

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

3G	Third Generation mobile technology
ATR	Automated Target Recognition
BFT	Blue Force Tracking
C2	Command and Control
C4ISR	Command Control, Communication, Computers, Intelligence, Surveillance, and Reconnaissance
CD&E	Concept Development & Experimentation
CI	Critical Infrastructure
COA	Courses of Action
COP	Common Operating Picture
COP of CI	Common Operating Picture of Critical Infrastructure
COTS	Commercial off-the-shelf
CPS	Cyber Physical System
DiSCI	Digital Security of Critical Infrastructures
DM	Decision Making
DOD	Department of Defense (note: used to refer to the U.S. DOD in this dissertation)
GDTA	Goal-Driven Task Analysis
GPS	Global Positioning System
HCI	Human-Computer Interface
ICE	Internet Connections Engine
ICT	Information and Communications Technology
IDS	Intrusion Detection System
IS	Information Systems
IoT	Internet of Things
IPS	Intrusion Prevention System
JDL	Joint Division of Laboratories
MANET	Mobile Ad Hoc Network
MUSAS	Mobile Urban Area Situation Awareness System
NDI	Non-Developmental Items
OODA	Object-Orient-Decide-Act
OTS	Off the shelf
PDA	Personal Digital Assistant
RO	Research Objective
SA	Situation Awareness
SACIN	Situation Awareness of Critical Infrastructure and Networks system
SAGAT	Situation Awareness Global Assessment Technique
SAN	Sensor Actuator Networks
SAOD	Situation Awareness-Oriented Design
SART	Situation Awareness Rating Technique
SASO	Stability and Support Operations
SAW	Situation Awareness (term is being used by some proceedings referred by this dissertation)
SCADA	Supervisory control and data acquisition system
SHODAN	An internet search engine for discovering devices and computers
SLAM	Simultaneous Location and Mapping
SME	Subject Matter Expert
SOA	Service-Oriented Architecture

SSO	Source System Operator
SSW	Smart Sensor Web
SUS	System Usability Scale
SUO SASS	Small Unit Operations Situational Awareness System
UAV	Unmanned Aerial Vehicle
UI	User Interface
VHF	Very High Frequency (refers to frequency band from 30 MHz to 300 MHz)
WASA	Wide-Area Situational Awareness (methodological framework)
WiFi	Wireless Local Area product compatible with IEEE 802.11
WLAN	Wireless Local Area Network
WISM II	Wireless sensor systems in Indoor Situation Modelling II
WSN	Wireless Sensor Network
WSP	Wireless Sensor Platform

LIST OF FIGURES

LIST OF TABLES

DEFINITIONS

Ad Hoc is a solution formed or used for specific or immediate problems or needs. [1]

Architecture is the manner in which the components of a computer or computer system are organized and integrated. [2]

Command and Control refers to the exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission. Also called **C2**. [3]

Commercial off-the-shelf product is one that is used "as-is." COTS products are designed to be easily installed and to interoperate with existing system components. [4, 5]

Common Operating Picture is a single identical display of relevant information shared by more than one command. A common operating picture facilitates collaborative planning and assists all echelons to achieve situational awareness. Also called COP. [6]

Concept is a notion or statement of an idea, expressing how something might be done or accomplished, which may lead to an accepted procedure. [7]

Cloud-based computing is the practice of storing regularly used computer data on multiple servers that can be accessed through the Internet. [8]

Critical Infrastructure is an asset, system, or part located in member states, which is essential for the maintenance of vital societal functions, health, safety, security, economic, or social well-being of people, and the disruption or destruction of which would have a significant impact in a member state as a result of the failure to maintain those functions. [9]

Cyber is something relating to, or involving computers or computer networks (as the Internet). [10]

Cyber-Physical Systems are co-engineered interacting networks of physical and computational components. These systems will provide the foundation of our critical infrastructure, form the basis of emerging and future smart services, and improve our quality of life in many areas. [11]

Data Fusion is identified as the integration of data and knowledge from several sources. [12]

Government off-the-shelf product is typically developed by the technical staff of the government agency for which it is created. [4]

Human Factors is a body of knowledge about human abilities, human limitations, and other human characteristics that are relevant to design. [13]

Information fusion is a term that typically is used synonymously with data fusion. In some cases, it is used to refer to information from a higher abstraction level (already processed data) compared to data fusion (raw data from sensors). [12]

Modifiable off-the-shelf product is typically a COTS product whose source code can be modified. [4]

Off-the-shelf means a product or a service available as a stock item that is not specially designed or custom-made. [14]

Proof-of-concept is evidence that demonstrates that a business model or idea is feasible. [15]

Schema is a mental codification of experience that includes a particular organized way of perceiving cognitively and responding to a complex situation or set of stimuli. [16]

Service-oriented architecture is a loosely coupled architecture designed to meet the business needs of the organization. [17]

Situational awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and a projection of their status in the near future. [18]

Systems design is a process of defining the hardware and software architecture, components, modules, interfaces, and data for a system to satisfy specified requirements. [19]

User-Centered Approach is a design model created by Mica Endsley and Depra Jones. The model presents foundations for user-centered design. [20]

1

INTRODUCTION

In a modern society, situation awareness (SA)[21] is critical for various levels of decision makers in different environments. A tool for enabling good level of SA is Common Operating Picture (COP) [6]. A good level of SA enables improved decision-making (DM) capabilities and accurate responses to situations as they arise. Usually, combining information from several systems is a key aspect in different applications, which enables context-aware data gathering, analysis, and decisions, and aids in maintaining SA. In modern systems, the actual limitations are no longer restricted to discovering the information but by the processing speed of human operators. For this reason, the topic of automation and information fusion have more importance in the creation of platforms where the human analyst is able to operate. Moreover, in several environments, technical devices are the only source of information for the operator; this is the situation especially in the monitoring room environment.

In many projects, the approach to the common operating picture (COP) is to rely first on technology [20]. In this dissertation, the approach is to discover the information needs, which are then addressed with a proof-of-concept system and evaluated in retrospect to fit the scenario. In this research, two different use cases are examined and presented. The environments are different but the main task for the support systems is the same: the creation of adequate SA for the end user.

1.1 Context of the research

Military sciences focus on military processes, institutions, and behavior along with the study of war and warfare [22]. This research focuses on military technology and on this basis presents technical solutions for existing or new problems. The approach is highly connected with the science of information technology and software engineering, which is a branch of information technology [23].

This research seeks to present novel approaches in order to support the operator's situation awareness in a complex environment. The approach is technical; the recognized challenges are addressed using suitable conceptual, architectural, and design means. Finally, the level of SA is verified using certain means of measurement. The approach is at a system level and the presented proof-of-concept systems are partially implemented samples from the designed entity in order to permit the end user tests. The research field is in the military sciences, which enables a system-wide perspective.

Using the terms of NASA technology readiness levels [24], the presented concept systems in this dissertation will be located in levels 2 and 3 where the initial concept has been applied to evaluate the practical application of the systems. The purpose of the development is not to proceed to higher levels, as this is university research. If these systems were to be brought into use, the core part would be the concept and architecture; the implementation would be done from the start as a part of the productization process.

1.2 Structure of the dissertation

This dissertation is divided into six main chapters. Chapter 1 starts by explaining the related work, research objectives, research questions, research process and limitations of the study. In chapter 2 the theories and models are discussed. Chapter 3 presents the different methods used. In Chapter 4, the implemented test systems, concepts, and architectures are discussed. Chapter 5 presents the results of the dissertation in relation to the research objects. Finally, Chapter 6 concludes the dissertation by discussing the contributions of the dissertation and proposes future research topics.

1.3 Related Work

In some cases, situation awareness (SA) is seen as a tremendous amount of data coming from multiple sources. Ruiz and Redmond provide an excellent analogy originating from the field of aviation: the flight controller is not being displayed the raw radar signals in line format; instead, the aggregated information coming from multiple sources is being displayed on the radar screen containing information such as altitude, direction, identifier, and location. Even the estimation of the flight path based in these attributes is displayed. [25] The same kind of fusion and aggregation can be used in the world of Cyber Physical System (CPS) SA. Critical Infrastructure (CI) SA has all the same elements and preconditions as in traditional SA, but it differs from the mechanisms of how it is achieved. As explained by Ruiz and Redmont, the Command and Control (C2) systems in contrast are typically focused on geospatial thinking. This aspect is different in the CPS where assets are more widely dispersed. The C2 process is focused on the idea of centralized control and decentralized execution; this does not change in a CPS environment. A CI operator focuses on geographical, logical, and physical systems. An effective C2 system must compress the amount of information and project courses of actions (COA) to the commander. [25]

1.3.1 Common operating picture systems

A COP can be seen as an object of a structure or as a multipurpose repository hosting knowledge [26]. As this study focuses on the information that is delivered to the user, it is natural that this section also takes special account of the COP with the aim of forming a user-specific COP with different solutions. The transformation from physical maps toward computerized procedures begun in the 1990s [27].

Loomis et al. have presented a user-defined COP in [28]. The approach is network-centric and enables the use of multiple information sources. Their solution provides a hierarchical model of COP as well as a layered structure for information delivery. The relation to decision making is also taken into account with the conjunction of

SA and the need for flexibility in the visual presentation. In addition, they present an architectural framework to support these goals. [28]

Butler et al. presented the Global Command and Control system (GCCS) COP in 1999. The system is a continuation work for World Wide Military Command and Control systems (WWMCCS), which have been in use by the US military for 20 years. Their goal was to use existing commercial products and reduce the complexity of the existing systems. The system is for long distance use and the approach is technical. This work focuses on software architecture and messaging framework of the system. They also present security features but focus more on architecture than COP or SA. [29] A key feature in combining the operational dimension with the technology level is the common understanding of the issue and effects as well as the possibilities. Balfour et al. have addressed this issue in [30], where they discuss the confidence factors of commanders in computer network operations.

The concept of the Deployable Emergency Information Sharing (EIS) Framework is presented by Balfour in [31]. It focuses on real-time delivery of information to emergency responders, managers, organizations, and even citizens. EIS aims to enable shared situational awareness with a comprehensive architecture in a cloud-based environment. Balfour has also presented a service-based solution for the delivery of COP to the user with augmented reality [31, 32]

The concept of a Cyber Common Operating picture (CCOP) is examined in [27]. The authors also combine the operations in cyberspace as well as in traditional kinetic space. An important perspective is that of using automated decision making and taking into consideration the role of humans. It is clear that although the creation of COP in cyberspace is fast paced and requires the use of multiple devices, the role of humans is not to be underestimated. The authors also provide a listing of general tasks that a CCOP system should fulfill, and they acknowledge that the objectives are unrealistic for near-term solutions. [27]

Major task areas in CCOP include the following:

- Accurate real-time location (both physical and, where applicable, virtual) and status of cyber and kinetic forces, including friendly, neutral, and adversarial.
- The ability to provide machine- and human-based C2 of assigned friendly units throughout ongoing cyber operations.
- Seamlessly integrated displays and processing of information for the air, land, sea, space, and cyber domains.
- Appropriate situational awareness of the environment's tactical, operational, and strategic levels.
- Predictive analysis to anticipate enemy actions and reactions.
- Decision support to help leaders analyze options and make decisions across cyber/physical domain operations. [27]

The integration between different army branches is an important observation made in CCOP [27]. Any capability without links to each other or to the specific operation is in danger of going unused or the entire capacity going unrealized. In terms of the

CPS, this is even more likely as the capability is not usually directly linked to the C2 enabler and securer.

At the level of strategic crisis management, the European Commission has funded research, which is aimed at improving SA to the crisis managers. They have developed new solutions for the sharing and creation of COP on different projects [33, 34]. These projects highlight the need for 3D visualization and sharing the information. In addition, they have developed large-scale exercises to test the systems. The future work challenge in this area is stated to be in building interiors [35], which in fact is the main focus of the WISM II project [P III & P IV]. Imaging terrain to 3D is studied for example in [36-39], but the approaches are aimed at the outdoors. An interesting approach to indoors modelling by Google is Project Tango, in which the Android phone is used as a sensor for the creation of 3D map [40].

In terms of services-based systems for multi-sector solutions, some models exist. A solution based on service-oriented architecture (SOA) [41] is studied in [42]. In this solution, the role of SAW (the acronym used for Situation Awareness in this paper) is acknowledged at the services level. It is recognized that the composition of services can provide advantages. The approach focuses on creating SAW from the service coordination perspective and enables an understanding of the current service structure status [42, 43]. An interesting perspective to SAW is the ontology approach by Matheus et al. where they aim to present a general ontology that supports heterogeneous situations. The final goal is to allow the end user to make queries of the current situation for determining the possible future states. [44] The class structure might be proven usable in service-based implementations where SA is engineered inside the technology.

1.3.2 Dismounted forces systems

In the field of dismounted forces, information superiority over the enemy is essential for winning the battle. In this task, the system integration of command, control, communications, computers, intelligence, information, surveillance, and reconnaissance (C4I2SR) has a key role to play [45]. Having comprehensive SA can also help to minimize fratricide on the battlefield.[46]

Efforts to improve the level of SA are being made in many armies. The U.S. army Joint Vision document from 2001 [47] highlights the importance of information superiority throughout the battlefield. It is likely that the role of a soldier is moving toward a linked and sensor-based solution where the warrior is in fact both a sensor and an actor in the field. This also presents requirements for networking. [45] A report on soldier modernization [48] summarizes multiple different programs that are currently under development. Many programs aim to develop sophisticated information fusion capabilities and highly integrated systems, such as Future Combat Systems (FCS) [49] and Future Soldier 2030 [50].

The Small Unit Operations Situations Awareness System (SUO SASS) [51], uses ad hoc networks and location services focusing on soldiers in groups of small unit size. The perspective on COTS implementation and devices is also recognized in many studies [52, 53]. Diamond and Ceruti [54] present a model to support SA by utilizing COTS and sensor networks. A fast solution for deploying sensors to the battlefield would be to use ready technologies, such as IEEE 802.11, to enable distributed sensors, actuators, and controllers [55]. Optimized communication and distributed resources pose multiple challenges to the application and the subject has been studied in terms of military and crises, for example, in [46, 56, 57]. The dispersal of sensor data from the nodes is examined in [58] in a battlefield scenario. The solution uses sensor gateways, soldiers, and command posts as sensor types. The use of Wireless Sensor Networks for detecting moving targets on the ground is presented in [59]. This kind of performance would prove of value to the C4ISR systems. For the challenges in the detection, hybrid sensor network architecture is presented [59].

In urban operations, a map is an essential tool for the personnel to operate. A common understanding of the operating environment, reference, and direction is needed. As this information is usually not available prior to the operation, a robot performing dynamic mapping and locating itself can be a good alternative. [60] Many scalable and modular solutions and automated robots are needed for the theatre [61].

In the Swedish Defence Research Agency, a study has been performed about information fusion on the tactical domain. The researchers used a division-wide scenario enabling network-based defense in the C4ISR system. In this project, a priori information is combined with sensors in the field and aggregated according to the needs of the users. Information from road cameras, UAVs, ground sensor networks, and military units is utilized. [62]

The concept of a smart sensor web (SSW) is studied in [63]. It highlights the combination of the current intelligence, surveillance, and reconnaissance (ISR) and smart sensor web with a functional framework, which would enable an improved capability to resolve situations. The role of COTS products is also recognized. Spreading the battlefield with sensors provides the initial state, but the actual "smart" features are the automated recognition capabilities of the network, such as automated target recognition (ATR). The most important part to the warfighter is being recognized as fusion and visualization. [63] The different systems are presented in Table 1.

Dismounted forces					
	Off-the-Shelf	Blue force tracking	Simultaneous location and mapping	Locating indoors	Isolated usage
MUSAS	X	X	X	X	X
Future Combat Systems (FCS) [49]	X	X			X
Future Soldier 2030 [50]	X	X			X
SUO SASS [51]		X		X	X
Smart sensor web (SSW) [63].	X	X	X		X
IFD03 [62]	X	X			X

Table 1 - Dismounted forces

1.3.3 Monitor room environment and CI systems

In modern societies, CI plays a key role in keeping complex operations functioning. In almost every system, CI has its role: as either a defended domain or the target of operations. The CI consists of an extremely heterogeneous CPS [11] connecting the entities to each other and making the processes possible. A good example of CPS for CI is the smart grid. [64, 65] Threats to the CI fall into two distinct categories, physical threats and cyber threats [66]. In order to understand what is happening in the CI, the operator needs to be aware of both perspectives. Pederson et al. have performed a survey of the research in CI interdependency and identified the main activities in 2006 [67].

Alcaraz and Lopez present the wide-area situational awareness (WASA) methodological framework for enabling the SA creation from distributed systems with a low or no human presence. This focus is on improving the situational awareness of CIs. In addition to automation and normalization, they discuss threat analysis automation for the support of SA. [68]

An agent-based modelling and simulation (ASMB) framework is presented by Casalicchio in [69]. The agent-based approach is recognized as one of the most promising for studying the interdependencies of CI. The authors also leverage simulation frameworks for better understanding the dependencies. [69] The complexity and interdependencies are examined by Rinaldi et al. in [70]. They provide dimensions for interdependencies and explore the cascading events. Finally, the authors present a six-step taxonomy to describe the types of aspects of interdependencies (types of interdependencies, infrastructure environment, coupling and response behavior, infrastructure characteristics, types of failures, and state of operations). [70] In the field of smart cities, a framework for the operation in the CI response framework is presented to improve the operational capability of first responders. They also highlight the importance of the Internet of Things (IoT) as an enabler and information source. The base information comes from sensor actuator networks (SAN) from which the information is aggregated to the smart city. [71]

Tolone et al. approach CI from the perspective of modelling. They are developing approaches to the daunting task of identifying and understanding the vulnerabilities in an interdependent and cross-infrastructural society. They combine an agent-based approach and geographic information systems (GIS) for improving the SA and adopt brokered architecture for the task. [72] The interdependencies of CI are also examined in [73], where the concept of a copula from probability theory has been adopted. This paper divides dependencies as physical, cyber, geographical, and logical. Moreover, it proposes an algorithmic solution to examine the dependencies. In the field of complex system theory, Wang et al. provide a modelling framework in [74]. They state that CI is in fact a typical complex system with the characteristics of self-organization. They aim to abstract the nodes in CI for enabling measuring the CI [74]. Zimmerman proposes a method for constructing a catalog of infrastructure dependencies. The goal is to reduce the consequences of different events and to create foundations for the analysis of cascading events [75, 76].

In terms of visualization, Kopylec et al. have studied the relations between physical and cyber infrastructures. A special focus is on physical events creating cascading effects in cyberspace. A visualization engine for the creation of SA is also presented, which also addresses disaster planning. [77]

An example of the measures in protecting the CI is executive order 13636 – Preliminary Cybersecurity Framework. This order highlights a risk-based approach and collaboration [78]. In CI, the environment is based on multiple actors and teams, where the goal is achieving situational awareness. Challenges in terms of SA sharing are studied in the doctoral dissertation by Kannisto [79]. The features of different systems are presented in Table 2.

Monitor room environment and CI systems								
	Off-the-Shelf	Three-level-model	Joint Division of Laboratories	Agent	Brokered	Distributed usage	Dependencies and relations	Simulation
SACIN	X	X	X	X	X	X	X	X
Wide-area situational awareness (WASA) [68]		(X)*				X		
Agent-based modelling and simulation (ASMB) [69]				X			X	X
SCCIR: Smart Cities Critical Infrastructure Response Framework [71]						X	X	
Critical Infrastructure Integration Modeling and Simulation [72]				X	X		X	X

Table 2 - Monitor room and CI systems
*Context awareness

1.4 Research gap

The concepts of data fusion and HCI have been subject to several studies, as described in previous sections. As the process of gaining SA is different in every use case, the right sensor set and presentation methods are crucial. In addition, it seems to be difficult to find system-wide research, which would contain the data fusion, COP, and SA together (see sections 1.3.1–1.3.3).

In terms of dismounted operations, Table 1 presents the key differences between the examined systems. In many cases, a service-based or agent approach is applied to fill the information needs. The SSW is the closest project in many ways, but it lacks indoor location possibilities. The final goal in several systems is the same: improved SA for the end user. Still, a lack of applying the SA fundamentals to the architectural and technical level is apparent. The common approach is to design the user interface for the user's SA, but not to implement SA in the system itself. In the field of urban warfare, the location techniques indoors seem to be the challenging part in operations. Multiple solutions exist for outdoor use but when entering into buildings, a lack and creation of blueprints and locating one's own troops, hostile troops, or neutral troops using passive methods pose a challenge. Techniques for these issues exist, but the application for system-wide solutions is rare (see Table 1). These systems will be in active use as the technology evolves.

In the field of monitor room system environments, implementations where SA would be attached to an agent-based service structure were not discovered (see Table 2). In these environments, the approach usually focuses on modelling specific issues or a specific problem. It seems that the most common approach is to create an architecture, which addresses the issue, and hide the data fusion layer inside the work. Most commercial or military projects focus on system-level implementation, but these approaches naturally leave many details to the concerns of outsourcing or focus on older technology.

Based in the existing research the following gaps can be identified:

- Integration of the SA technical framework
- Application of data fusion to service-based solutions for the creation of the common operating picture (COP)
- Combination of indoor location techniques with the COP system in urban area warfare
- Combination of the architectures for heterogeneous environments

1.5 Research process

This dissertation consists of nine publications supporting the main research question (will be presented in 1.7). The comprehensive answer to research objective 1 (RO 1) can be found in publications [I–IV] where the focus is on a mobile solution in a heterogeneous and stressful environment. Publications [V–VIII] focus on studying the challenges and solutions in a nationwide use case as well as to the SA achieved by operators. Finally, RO 3 is studied in publication [IX], which gathers the challenges and solutions from RO 1 and RO 2 into a common architectural solution. These relationships are presented in Figure 1.

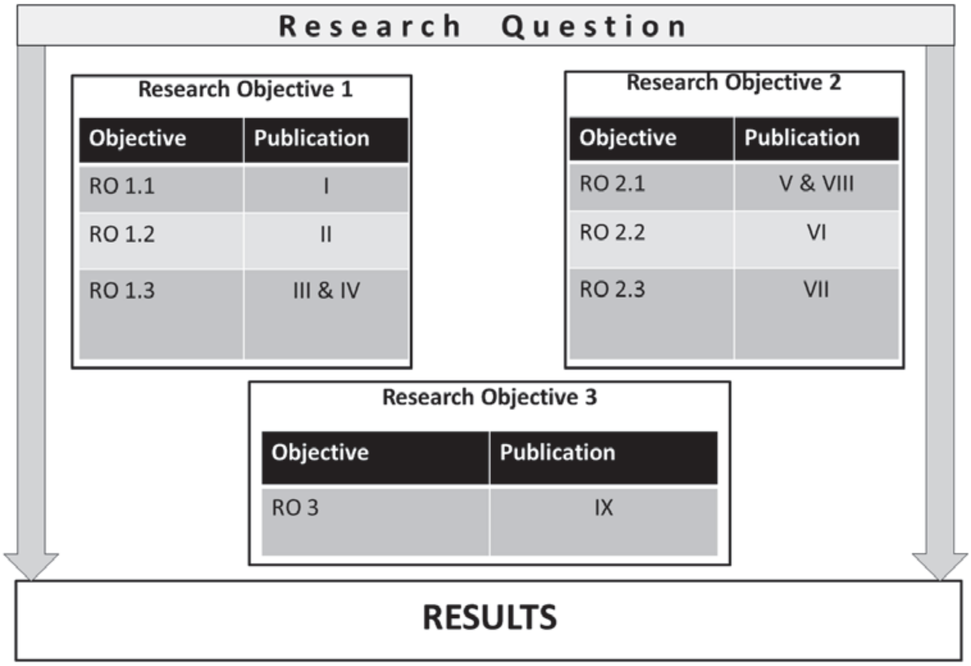

Figure 1 - Research objectives and publications

The research process adapted from the design science paradigm [80] is presented in Figure 2. The environment in the application domain focuses on military personnel and situation room environments in the fields of urban area operations and critical infrastructure. The existing knowledge base is identified in chapter 1.3, 2 and 3. In terms of information systems (IS) research the main artifacts are identified as MUSAS and SACIN systems, which are studied in the chapter 4 where the tests and results for the systems are also presented (justify and evaluate in Figure 2). Furthermore, the research gap is identified in section 1.4 and based in that the required functionality determined by the previous research is identified. Combination with chapter 1.4 and the chapter 5, Results and Conclusions, the additions to the knowledge base are determined. The main additions to the knowledge base are constructs, concepts and architectures (lower right in Figure 2).

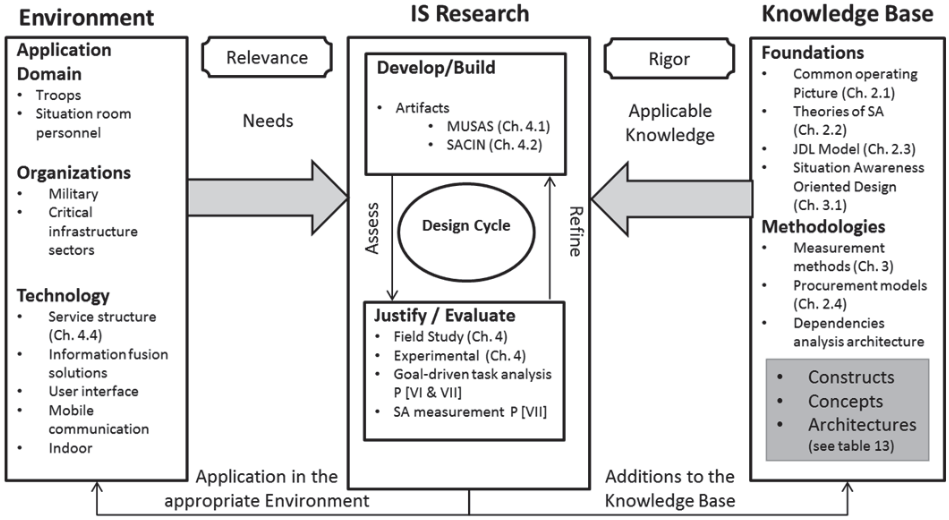

Figure 2 - Design science (adopted from [80, 81])

1.6 Research methods

In terms of the research strategies [82], the study combines experimental and empirical methods. Empirical approach enables the exploring of the object by experiences and observations of the studied object so it is well suitable for gaining understanding the phenomenon being addressed. Experimental methods enable the exploring and influence of the interaction in controlled environment in different test sessions.

The research mainly uses qualitative methods (e.g., opinions about the user interface), but selected quantitative methods are also included (e.g., measuring the level of SA at a given moment). The research paradigm is based on design science [80] as the research seek to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts.

The research focus is cross-scientific, as software engineering and empirical systems form the base of the research supplemented with the theories of SA. The dissertation includes features from the applied sciences branch, as the research creates contributions using existing scientific methods. The approach is technical and the dissertation uses the means of experiments and implementation to achieve new results and improvements.

In this research, the main research activities undertaken are as follows:

1. **Literature reviews** were made on each topic in the field of the selected components and concepts. As the approach is at the system level, a need for addressing multiple topics exists. These topics include, for example, SA and COP. This work can be realized from chapter 1.3 and chapters 2 and 3.

2. **Concept creation and prototyping**. With the created concepts, it is possible to evaluate the feasibility of the idea under study. Prototyping and proof-of-concept experiments also support the falsifiability of the created concepts. One focal research decision is to first design a concept, then implement it, and finally measure the results. This work is presented in chapter 4.
3. **Situation awareness measurement methods**. In order to understand the human computer interaction and define the feasibility, a set of SA methods is used. The results can be discovered in detail from the publications and from chapter 5. The methods are described in chapter 3.
4. **Synthesis**. As a result of the literature reviews, concept creation, and prototyping as well as SA measurement, a model for a technical concept for sharing SA is presented. These aspects are described in chapter 5.

1.7 Research question and objectives

The methodology of software engineering is not straightforward [83, 84]. One approach by Shaw is to examine what kinds of questions are worth investigating. According to Shaw [83], the scientific and engineer fields can be characterized by identifying what they value:

- What kinds of questions are "interesting"?
- What kinds of results help to answer these questions, and what research methods can produce these results?
- What kinds of evidence can demonstrate the validity of a result, and how are good results distinguished from bad ones? [83]

With this background, the type of research questions can be divided into five groups. This thesis addresses two distinct types, which are 1) *method or means of development* and 2) *feasibility*. The approach to the research questions is design based [85]. This approach can be identified from the research questions, which are presented below. This work aims to discover how the present situation can be improved and what the effective ways of achieving the desired result are.

The focus of the dissertation is in the benefit of the system to the users, therefore the main research question is as follows:

Is it possible to support situation awareness with a common operating picture in two different environments with off-the-shelf technology?

The study is divided into three main research objectives to support the main research question, which are presented in Table 3. Objective 1 is focused on SA in urban area operations and RO 1.1–1.3 support this theme. RO 2 focuses on the situation room environment while RO 3 combines the two environments. The main research question and RO 1–3 are examined and tested using the sub research objectives (1.1–1.2 & 2.1–2.3). The core arguments are gathered using the proof-of-concept systems implemented in RO 1.1–1.2 and 2.1–2.3 and 3.

OBJECTIVE	QUESTION
RO 1: Does multi-sensors-enabled data fusion provide value and support SA in dismounted operations in an urban area?	
RO 1.1	Would a shared service structure provide advantages in the creation of a COP in shared C2 systems?
RO 1.2	Is it possible to improve a tactical wireless local area network (WLAN) with decentralization?
RO 1.3	Does information integration and shared sensor structure enable the improved performance of dismounted troops with off-the-shelf technology?
RO 2: Is it possible to support SA in a situation room environment in terms of critical infrastructure?	
RO 2.1	Is it possible to create and share the COP of critical infrastructure with off-the-shelf technology?
RO 2.2	What are the requirements for a critical infrastructure operator in terms of a COP?
RO 2.3	Is it possible to visualize a COP of critical infrastructure so that it supports SA?
RO 3: Is it possible to support SA in different environments with a common service architecture?	

Table 3 - Research objectives

1.8 Research limitations

The approach in this work is technology oriented where the user plays a large role in the created solutions in defining what needs to be accomplished and how well it is achieved. As discussed in the previous subsection, the goal is not to create a product and, for this reason, a set of limitations will be presented to illustrate the scope.

- Human factors
  - In this research, the effect of human factors is recognized, but it is not examined to a further degree, as the approach is technical. The approach aims to measure the levels of SA in order to qualify the results achieved in the implementation.
- Full complexity of systems
  - The scope is on creating new concepts and architectures, not on validating the operational resilience. Accordingly, the limitations include test cases in real-sized environments. At the conceptual level, the challenges will be noted but not necessarily implemented.
- Information security
  - Proof-of-concept systems are not made to face real environments. The aspects of targeted cyber-attacks or other hostile acts toward the implemented systems are not covered in the design.
- Connectivity
  - The full connectivity is not implemented, but the connecting interfaces are identified and briefly described.

As the approach focuses on the creation of the concept and architecture, these entities will include features from the objects in the list of limitations, but such features might not be implemented in the proof-of-concept systems.

2

THEORY AND MODELS

This chapter will present the key theories and models behind the implemented systems. The chapter starts by presenting the final goal of a system to exist: building and supporting situation awareness (SA) using a common operating picture (COP). Three approaches to SA are covered. The model used in this study as a main approach is the three-level model by Endsley [86]. Finally, the chapter is concluded in the model of data fusion and procurement models. The common theme behind these topics is in the implemented systems; all of these theories and methods have been adopted to use in the created systems.

2.1 Common operating picture

A COP can be seen as the tool for delivering the information to the user. Naturally, different displays are the most common way of delivering the COP and, in the cyber environment, it is usually the only option. In the military environment, the usage of whiteboards and paper can be an important way of updating COP but with modern systems, automation usually overcomes the advantages of manually maintaining the COP. This is a consequence of large amount of deployed sensors and data coming to the systems. As the level of detail is vast and the update interval increases, a computer is more efficient solution for the task. A COP is a tool for the commander or person in charge to solve problems using command and control (C2) systems [87]. The technical systems as such are usually not within the reach of the end users, but the provided user interface might be the only source of information to the user. In the 1980s, some research studies were performed on large group displays, which were used for team situation awareness. According to McNeese, COP can be seen as an extension of large group displays (LGD).[26] COP is widely used paradigm in many environments and especially in military it is well suitable for a baseline component in creation of SA.

By definition, a COP, according to the US Department of Defense, is as follows:

> A single identical display of relevant information shared by more than one command. A COP facilitates collaborative planning and assists all echelons to achieve situational awareness. [6]

This definition might need to be extended when the size and users of the system increase. The definition most likely originates from the traditional military perspective where geospatial relations and mission tasking are the core business. In cyber physical systems (CPS), the services are widely spread and their impacts cannot be presented in a geospatial display in all cases.

The integrity of the provided COP is also important. In C2 environments, the COP is usually compiled by the commander's staff and it consists of subjective components. If the COP lacks precision in one crucial aspect, it presents the danger of the integrity of the entire COP being labeled as untrustworthy. This can result in a situation where the commander decides not to use the provided COP. In [88], Robertson has combined confidentiality, integrity, availability, authenticity, and non-reputation with the COP process, as the building and sharing is largely reliant on ICT infrastructures and models [88].

As with any system, COP systems need to have a purpose for why they are being used. The natural response for this need is SA, and in some cases, COP is the only source of SA. As technology has taken a large role in building and automating the process, the role of the human operator is changing. Computers and networks are the main workers in the technical process but the role of the operator remains important. In COP systems trustworthiness is crucial for if the COP is not trusted, it usually is not used or is otherwise disregarded.

2.2 Situation awareness

According to Gilson [89], the concept of situational awareness (SA) was first presented by Oswald Boelcke during the First World War. Boelcke was a fighter plane pilot who participated into several aerial fights during his career and contributed to the field of theories of fighter plane fights. [89]

According to Boelcke, the concept of SA consisted of the following:

> 'The importance of gaining an awareness of the enemy before the enemy gained a similar awareness, and devised methods for accomplishing this.' [89]

The definition of SA ever since has been under revision by multiple actors in the field. Beringer and Handkook [90] have made a comprehensive collection of the definitions in multiple contexts. As for the approach methods, Stanton has divided the three approach methods as the three-level model, the cognitive sub-systems approach, and the perceptual cycle [91]. In the following bullets, these three different definitions are presented:

- SA is the perception of the elements in the environment within the volume of time and space, the comprehension of their meaning, and a projection of their status in the near future [18].

- SA is the conscious dynamic reflection on the situation by an individual. It provides a dynamic orientation to the situation, the opportunity to reflect not only the past, present, and future, but also the potential features of the situation. The dynamic reflection contains logical-conceptual, imaginative, conscious, and unconscious components, which enables individuals to develop mental models of external events. [92]

- SA is the invariant in the agent-environment system that generates the momentary knowledge and behavior required to attain the goals specified by an arbiter of performance in the environment [93].

The comparison adopted from [94] is shown in Table 4. The above definitions are linked to the theories presented in the table.

Theory	**Three-level model [86]**	**Perceptual cycle [93]**	**Activity approach [92]**
Origin	Aviation	Air Traffic Control	N/A
Applications	Military, Air Traffic Control, Aviation, Driving, Nuclear Power	Air Traffic Control	N/A
Theoretical background	Information Processing Theory Recognition-Primed Decision-Making Model [95]	Perceptual Cycle Model [96]	Theory of Activity Model [92]
Process	Perception of elements Comprehension of meaning Projection of future states	Schema-driven exploration & modification	Orientation Stage Executive Stage Evaluative Stage
Composition	Perception, comprehension, and projection of SA elements	Externally directed consciousness	Incoming Information Goals Conceptual Model of Situation Past Experience Environmental Features Motivation toward task goals Subjectively relevant Task Conditions
Measure	SAGAT [97] SA Requirements Analysis [98]	Task Performance Risk Space [93]	N/A
Process or product	Product	Process & Product	Process & Product
Strengths	1. Simple intuitive description of SA 2. Division of SA into levels is neat and permits measurement using the SAGAT approach 3. Holistic approach that considers factors such as system & interface design, workload, and training	1. Dynamic description of SA acquisition, maintenance and update of schema 2. Sound theoretical underpinning 3. Completeness of model is attractive, i.e., it describes both the process of acquiring SA and the product of SA	1. Model offers a more complete, dynamic description of SA than the three-level model 2. Clear description of each functional block's role in SA acquisition and maintenance is useful 3. SA described as a distinct and separate entity
Weakness	1. Fails to account for the dynamic nature of SA 2. SA process-oriented definition is contradictory to the description of SA as a "product" comprising three levels 3. Based on ill-defined and poorly understood psychological models (e.g., information processing, mental models)	1. Does not translate easily to SA description and measurement 2. Limited applications 3. The actual correlation between SA and performance is complex and not yet fully understood	1. Limited application and the model lacks supporting empirical evidence 2. Underpinning activity theory remains unclear 3. No measurement approach suggested

Table 4 - SA comparison adopted from [94]

The term SA is used in a broad manner. In addition, it seems that the wider audience does not necessarily see SA as a mental model, but rather as something that can be bought in the form of a product. Endsley also noted that the word needs special attention in being defined or the results may be poor [86]. Boyd's Object-Orient-Decide-Act loop model [99] has many similarities with Ensley's model. Boyd is more oriented to the process leading toward the actions while Endsley's focuses on SA and how it is formed in one's mind.

2.2.1 Three-level model

A widely used model is the three-level model by Mica Ensley [86]. This model describes three levels of SA: perception, comprehension, and projection. These levels are used to describe the cognitive models' state in one's mind. Endsley's model also correlates well with the Joint Directories of Laboratories (JDL) model of data fusion, which can be further used in creating specific layers of implementation supporting SA, as presented in [100].

Perception of elements in the environment (level 1 SA)

The forming of SA begins with perceiving the different variables from the environments, such as status, attributes, dynamics, and relevant elements in the environment. This level includes only the process of monitoring and detecting the different variables of the environment. This will provide the understanding of the elements in the environment (objects, events, people, systems, environmental factors) and their current state (locations, conditions, modes, actions). This phase can be seen as raw information gathering, which provides the building blocks for later levels. If the results in this layer are inadequate, the odds of gaining a good level in other layers decrease dramatically. [86]

The question to respond to in this phase is: "What are the current facts?" [101]

Comprehension of the current situation (level 2 SA)

The next step in SA formation involves a synthesis of disjointed Level 1 SA elements through the processes of pattern recognition, interpretation, and evaluation. This includes developing a comprehensive picture of the world, or of that portion of the world of interest to the individual. The levels are based on level 1 information, but includes more than just acknowledging the elements; they also depend upon a holistic understanding of the significance of events and elements. Moreover, each level includes the consciousness of the goal or mission to be accomplished. Different operators will create a different level 2 comprehension, as the education, training, and experience are also effective in the layer. [86]

The relevant question for this layer is: "What is actually going on?" [101]

Projection of future status (level 3 SA)

The third and highest level of SA involves the ability to project the future actions of the elements into the environment. Level 3 SA is achieved through knowledge of the status and dynamics of the elements and comprehension of the situation (Levels 1 and 2 SA), and then extrapolating this information forward in time to determine how it will affect the future states of the operational environment. This layer contains the temporal and spatial layers. Time is an important concept in SA in terms of changing at a tempo dictated by the actions of individuals, task characteristics, and the surrounding environment. [86]

The relevant question in this layer is: "What is most likely to happen if?" [101]

The basic model is demonstrated below in Figure 3. This model describes the relation of SA to the environment and it reflects the fact that SA is a tool for making the right decision at the right time and it has a process nature of learning. It also clarifies the role of experience and training in the process.

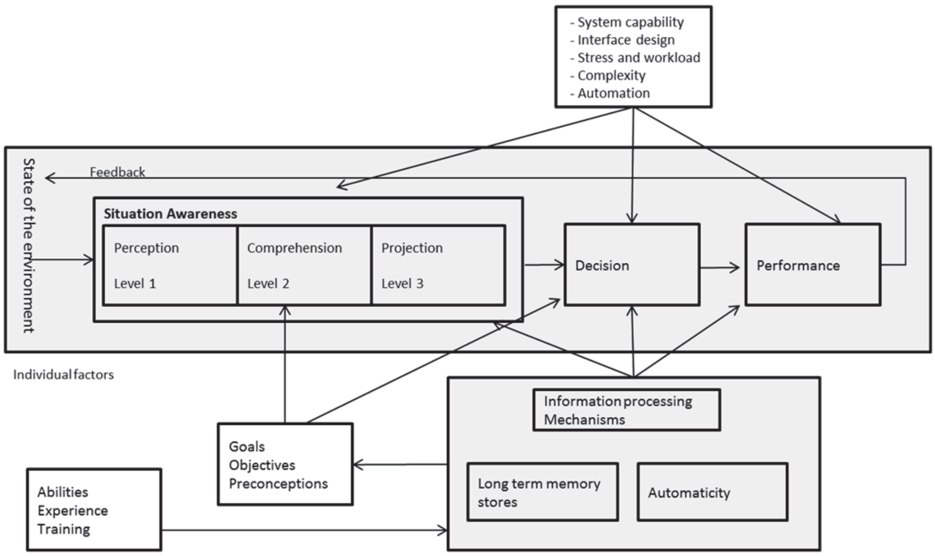

Figure 3 - SA process [86]

On top of Endsley's three-level model, means have been built in for quantitatively measuring the level of SA. The models operate as a great aid for researchers trying to discover improvements in SA. An example of this would be SAGAT (Situational Awareness Global Assessment Technique) [102]. Jones and Endsley have also presented an error taxonomy based on the locations where SA forming was inadequate. These results point to the source of errors, which can be located at level 1 and in more detail to the failure to observe or monitor data. [103] This result implies that the main cause of errors is present in the earliest state of observing, then creating cascading effects. The error taxonomy is presented in Table 5.

LEVELS	Descriptions of error types	Percentages
Level 1 SA	Data not available	13%
	Data hard to detect or discriminate	11.1%
	Failure to observe or monitor data	35.1%
	Misperception of data	8.7%
	Forget data	8.4%
Level 2 SA	Lack of, or incomplete, mental model	6.9 %
	Use of incorrect mental model	6.5 %
	Over-reliance on default values	4.6 %
	Other	2.3 %
Level 3 SA	Lack of, or incomplete, mental model	0.4 %
	Over-projection of current trends	1.1 %
	Other	1.9 %

Table 5 - Error types in SA [91]

As an addition to the original model, McGuiness and Foy present a level 4 named resolution. This layer would answer the question, "What exactly shall I do?" [101]

The model has been criticized as being a linear approach preventing the transformation from earlier levels before the current one is ready [104, 105]. Endsley responds to this criticism by pointing out that the model is not linear by nature, but if the SA is better in the lower levels, the evaluation is more likely to be successful in latter levels [106]. In addition, there has been debate whether the model is actually process or product oriented. For example, [107, 108] have pointed out that the model represents product separate from the process. According to Endsley [106], this is not the case and the dynamic process is in fact supported by the model. In [106], Endsley responds to the most common criticism given for the model.

2.2.2 Activity approach

Interactive sub systems are based on the theory originally presented by Bendy and Meister [92]. The systems consist of eight functional blocks, which divide the SA into a set of dependent entities, in which the state of each block depends on the feeds from other blocks. The forming of SA is described as links between the entities. The main difference from other models is that this model does not define processes such as perception, memory, thinking, or execution. [91] The building blocks are presented in Figure 4.

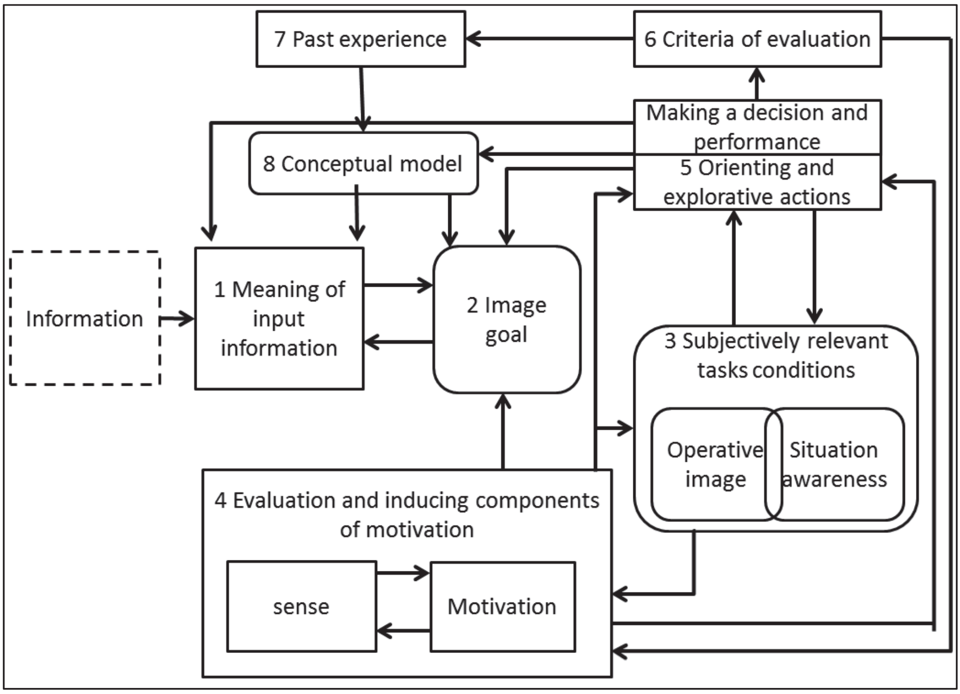

Figure 4 - Activity model components [92]

The functional blocks in the model perform the task of comprehending the meaning of the situation. Each block has its own mission in creating the SA and structure of activity. The function and summary of the blocks' roles are shown in Table 6. [92]

Block	Function	Input Block	Summary of Role
1	Meaning	0, 2, 5, 7	Interpretation of information from the world
2	Image	1, 4, 5, 8	Conceptual "image" of information-task-goal
3	Conditions	4, 5	Dynamic reflection of situation and task
4	Evaluation	3, 6	Comparison of motivation and performance
5	Performance	3, 4	Interaction with the world
6	Criteria	4, 5	Determination of relevant criteria for evaluation
7	Experience	6	Modification of experience to interpret new information
8	Model	7	Modification of world model to interpret new information

Table 6 - Functional blocks in activity approach [92]

Information arrives from the sensory-perceptual system to block 1 from where it is interpreted using block 8 (conceptual model), block 2 (image goal), and block 5 (orienting and explorative actions). [92]

The blocks define the tasks to be performed in creating the SA. This model does not contain a process model, rather, it is more focused on a product-like perspective. The model receives criticism from Stanton et al. [91], who argue that the model is incomplete in terms of the relations of the blocks as well as the model's relation to the world.

2.2.3 Perceptual cycle

The term perceptual cycle (also known as the cyclic model of perception) was introduced by the U.S. psychologist Ulrich Neisser. This model takes the process perspective, and it describes the information-processing model as a train of processes that arises from the middle of the apparatus. [109] The model approaches SA with the hypothesis that SA is neither resident in the world nor the person; it resides within the interaction between the person and the world [93].

Neisser presents the creation of consciousness as a process in which there are different processing points that eventually create consciousness; this is visualized in Figure 5. Neisser also emphasizes that perceptual activity is not bound to a single component, as even newborn babies will respond to noise and look instantly in the direction of a sound. [109]

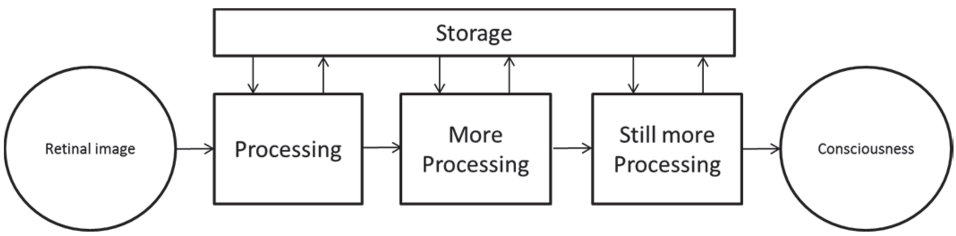

Figure 5 - Process in perceptual cycle approach [109]

One perspective is the anticipation that the mental model will lead to a prediction based on the model itself. This model does not describe predictable components that would support anticipated results [91]. The perceptual cycle is presented in Figure 6 by Neisser in [96].

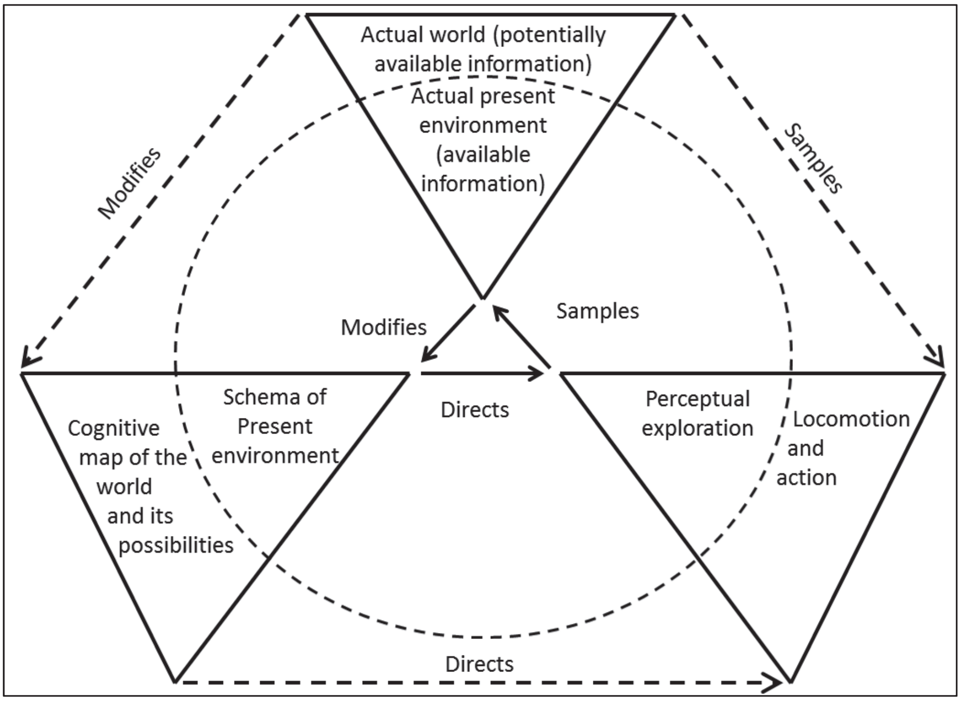

Figure 6 - Perceptual cycle [96]

When the events are happening, the environment is sampled. This information modifies and updates the internal schema. Moreover, this will point the way forward into further research and the model can be used to explain human behavior in control rooms without the preconditions created by other models. [91]

2.3 Joint Division of Laboratories (JDL) model

Data fusion is the process of combing data entities from multiple sources in order to improve the accuracy and big picture of the event horizon, resulting in an informal presentation of information. Data fusion processes can be categorized as low, intermediate, or high, where lower is the fusing of several elements of raw data being fused to produce a new stream of raw data. [110] In this dissertation, the model used in data fusion is the Joint Division of Laboratories model (JDL) [111]. The model is well suited for the purpose as it is well known and the most widely used model of data fusion. [112]

The Data Fusion Lexicon, produced by the JDL Data Fusion Subgroup in 1987, defined data fusion as follows:

> "A process dealing with the association, correlation, and combination of data and information from single and multiple sources to achieve refined position and identity estimates, and complete and timely assessments of situations and threats, and their significance" [111].

The JDL data fusion model is a framework that combines a set of policies for reconstructing sensor data in order to improve situational awareness. The JDL sensor fusion model was originally presented in 1988, and later refined in 1999 [112]. The process is characterized by continuous refinements of the estimates and assessments and the evaluation of the need for additional sources, or modification of the process itself, to achieve improved results [111]. The model divides data fusion into five categories, each having its own specific task in the process focusing on the results of the previous level. The adopted JDL model from [112-114] is presented in Figure 7.

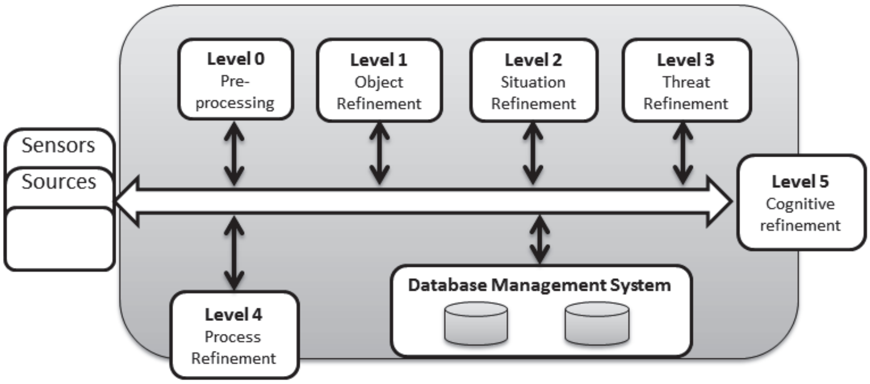

Figure 7 - JDL model [112-114]

The main task of **Level 0** (Source Preprocessing) is to reduce the processing load of the fusion processes by prescreening and allocating data to the appropriate processes.

Level 1 (Object Refinement) focuses on delivering products such as position and identity and classification characteristics such as features. This level performs data alignment (transformation of data to a consistent reference frame and units), association (using correlation methods), tracking actual and future positions of objects, and identification using classification methods.

Level 2 (Situation Refinement) gathers relations between the entities. The level aims to find a contextual description of the relationship between objects and observed events. In this phase, the contextual analysis is started for level 1 products and it will provide behavioral characteristics such as events and analyze activities.

Level 3 (Threat Refinement) provides threat assessment and estimates lethality, intent, and other higher-level intelligence functions. Based on a priori knowledge and predictions about the future situation, this processing level tries to draw inferences about vulnerabilities and opportunities for operation.

Level 4 (Process Refinement) can manage the sensors and allow fusion process refinement. The level is a meta process that monitors system real-time performance and reallocates sensors and sources to achieve particular mission goals.

Level 5 is the interface between the system and the user and it delivers the actual result.

The sources provide information from a variety of data sources, such as sensors, a priori information, databases, and human input. The responsibilities of the database management system include monitoring, evaluating, adding, updating, and providing information for the fusion processes.
[111, 114, 115]

Endsley's three-level model has been combined with the JDL model by Tadda and Salerono in [100]. This model is a proposed solution for a cyber-related infrastructure. Probably one of the best observations in the supplemented model is the role of humans and individuals' mental state; humans are the reasons why these systems exist. The model is presented in Figure 8. [100]

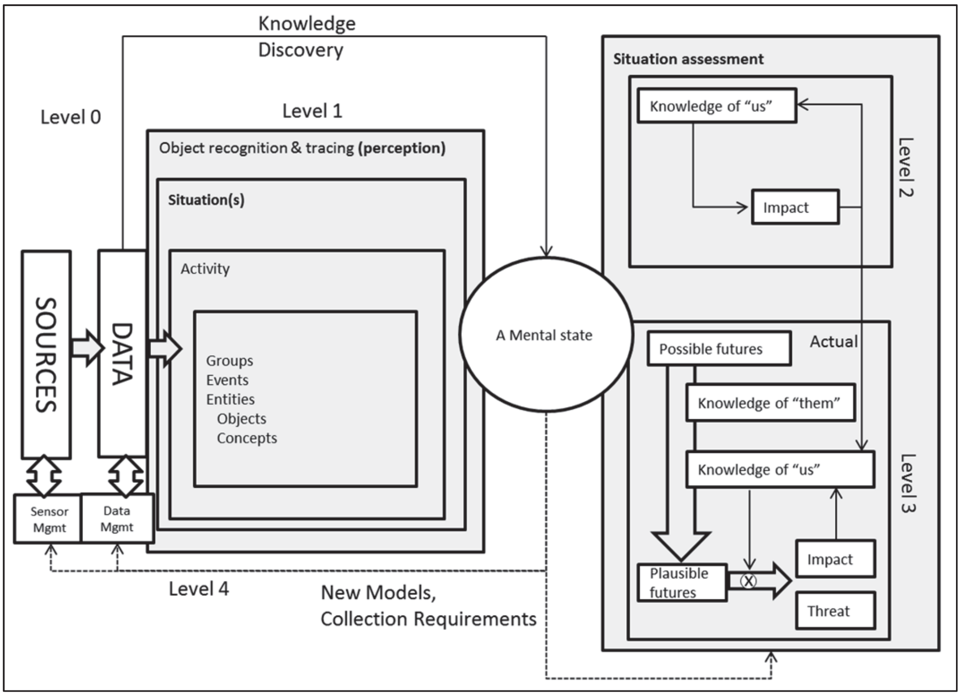

Figure 8 - Three-level model in the cyber environment [100]

The JDL model is widely used in military and civilian domains, but it also has its drawbacks. As the model is data centered, there might be difficulties in reusing the model. The model is abstract so addressing real-world challenges is not straightforward. The model does not guide the developer to the desired model or take a stand in architectural definitions. [115, 116]

2.4 Procurement model

When creating a model for a system to be deployed, usually the procurement model has to be taken into account. The increasing effort worldwide on cutting expenses and making smarter solutions has guided many organizations toward examining the possibility to use existing products and not creating everything from scratch. One way to achieve this is to examine different options using COTS (commercial- off-the-shelf) devices that would be able to provide nearly the same level of performance compared to military specific (mil-spec) with reduced costs. [117] Off-the-shelf (OTS) products refer to products or services, which are not specially designed for the intended use or customized [14]. The OTS products can be separated by their procurement strategy as follows:

- A **COTS** (commercial off-the-shelf) product is one that is used "as-is." COTS products are designed to be easily installed and to interoperate with existing system components. The term refers to non-developmental items (NDI) sold in the commercial marketplace and used or obtained through government contracts. Almost all software bought by the average computer user fits into the COTS category: operating systems, office product suites, word processing, and e-mail programs are among the myriad examples. [4, 5]
- A **GOTS** (government off-the-shelf) product is typically developed by the technical staff of the government agency for which it is created. It is sometimes developed by an external entity, but with funding and specifications from the agency. Because agencies can directly control all aspects of GOTS products, these are generally preferred for government purposes. [4]
- A **MOTS** (modified or modifiable off-the-shelf, or military off-the-shelf) product is typically a COTS product whose source code can be modified. The product may be customized by the purchaser, by the vendor, or by another party to meet the requirements of the customer. In the military context, MOTS refers to an off-the-shelf product that is developed or customized by a commercial vendor to respond to specific military requirements. Because a MOTS product is adapted for a specific purpose, it can be purchased and used immediately. However, since MOTS software specifications are written by external sources, government agencies are sometimes leery of these products, because they fear that future changes to the product will not be under their control. [4]

One of the major advantages of COTS software, which is mass-produced, is its relatively low cost. It is argued by Alford [118] that when using COTS, operation and support can be 72% of the life-cycle costs, which is a very appealing number for many organizations. The downside is the lack of possibilities in further development as the products are sold according to the "as is" principle. [4, 5] Moreover, the typical COTS producer is driven by market forces, which may result in a short lifecycle and increased rate of changes for the product. The typical governmental organization has experience in requirements-driven, specification-constrained, and custom design systems. It might prove difficult for an organization to adopt the new procurement model, which is bound to the ever-evolving market. Despite these challenges, with COTS it is possible to achieve lower development cycles, improved acquisition, state-of-the art solutions, and lower costs. [119, 120]

In GOTS products, the developing agency maintains the possibility to affect the actual product and for that reason is able to get a specific solution, but usually with greater costs. MOTS, in contrast, consists of products that can be modified from the source and leverages the use cases of the product but will likely also increase costs. [4]

In MUSAS on SACIN, the OTS technology has been one theme for the entire development cycle. In order to ease and simplify the development, the end user devices and server software have been targeted as COTS. The server logic in both cases can be seen as GOTS as the implementation uses ready-made and commercially available tools, but the logic itself is implemented by the project team to address the key issues. In terms of MOTS, the SACIN agent would be an example of a component that could be procured using MOTS technology where the inner layers containing the logic would be modified to fit the needs. In Table 7, the procurement models of the two projects are summarized. The projects are discussed in depth in Chapter 4.

	MUSAS	SACIN
End user devices	**COTS** Android devices, attachments, accessories	**COTS** Computers, displays, accessories
Server software	**COTS** COP sharing, visualization	**COTS** COP sharing, visualization
Sensors	**COTS** Location sensors, hardware in sensors	**COTS & MOTS** Agent component, different ready-made sensor interfaces such as SCADA and IDS systems
Main Logic	**Proprietary development combined with GOTS** Information fusion, COP sharing, location algorithms	**Proprietary development combined with GOTS** Cascading dependencies processing, user interface development and measurement

Table 7 - Possible procurement models in the projects

3

METHODS

In chapter 3, different models of SA have been presented. This section will focus on the measures used in the research work to improve the effectiveness of the created solutions.

As the amount of information is vast, it is essential to recognize where the information is used and what is valuable in order to achieve the given tasks. Mica Endsley and Depra Jones have developed principles for user-centered design, which take into account the user, who is often forgotten from the equation when new products are being made. [20]

Endsley provides eight distinct principles of user-centered design, as follows:

1. Organize information around goals
2. Present layer 2 information directly – support comprehension
3. Provide assistance for level 3 SA projections
4. Support global SA
5. Support trade-offs between goal-driven and data-driven processing
6. Make critical cues for schema activation salient
7. Take advantage of parallel processing capabilities
8. Use information filtering carefully [20]

The most important measurement methods in the publications of this dissertation are the Situational Awareness Global Assessment Technique (SAGAT) [102], Situation Awareness Rating Technique (SART) [121], System usability Scale (SUS) [122], visual walkthrough [123], informal walkthrough [124], and eye tracing. A comprehensive evaluation of measuring the different methods of SA can be found in Salmon et al. [125]. In the context of this dissertation, the methods used to measure SA and usability are in Table 8.

Method	Measurement type	Objective vs. subjective	Usage
SAGAT	Direct	Objective	Defining goals, user-oriented service structure
SUS	Direct	Subjective	Evaluating implementation usability
SART	Direct	Subjective	SA performance measuring

Table 8 - Used methods

The user interface should be able to provide a simple and easy view for humans, but to the designer, this is an all but trivial task. Blasch [126] lists the main challenges in human perception as follows.

Limitations of human attention that the automation designer must keep in mind include:

- Perceptual Processing Limitations – Increased perceived difficulty attending to more than one thing at a time.
- Focus of Attention – Impact of the situation on the user in directing the attention and keeping it focused.
- Central Processing Limitations – Cognitive processes may be limited in number, which can occur at the same time.
- Memory – Long, working, short – relationship between attention, working memory, search, short-term retention.
- Modes of Attention – Top-down or bottom-up. [126]

3.1 Situation awareness-oriented design

Situation Awareness-Oriented Design (SAOD) is a set of methods that optimizes decision making and performance using a user-centered approach to build the UI. The process consists of three steps starting from goal-driven task analysis (GDTA), explained in the subsection 3.2, followed by a design phase leading to a measurement phase. The process evolves by using a loopback from measurement to the design phase. The SAOD design process is presented in Figure 9. SAOD includes fifty principles, which aim to create a design process that supports the end user's needs. The process ensures that the key information is present to support SA in designated interfaces. Moreover, the process will support comprehension and projection by displaying the information in a fused way and arranged by the needs for SA. The big picture of the operations is also maintained by presenting global SA in an easy-to-grasp format but also providing the key information to succeed in the mission. The support for multi-tasking in SAOD is also a valuable design paradigm. [20, 127-130] SAOD is scientifically proven as an effective design plan, which will support operators' SA and will focus on avoiding critical errors in design. [21, 131]

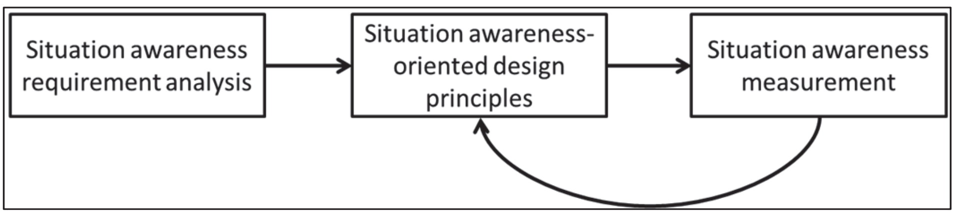

Figure 9 - SAOD design process [130]

3.2 Goal-driven task analysis

Before a system can be implemented, it is essential to recognize the SA needs of the users. For this purpose, a technique named goal-driven task analysis (GDTA) has been created. The technique seeks the answer to the question of what the operator would ideally like to know in order to achieve his or her goals. The nature of GDTA is dynamic; it focuses on information needs in a particular domain and does not collect static system requirements. The technique does not rely on technology and it can be used in various environments. The method is based on interviews with the subject matter experts (SME). The interviews are unstructured with a special focus on goals and information needs, not technology. The finished GDTA includes the overall goals, major goals, and sub goals, with decisions linked to the sub goals and SA requirements (see Figure 10). When the goal structure has been discovered, a firm foundation exists actually to start planning the user interface, as now it is known what information is needed to accomplish the operators' duties. [20, 132]

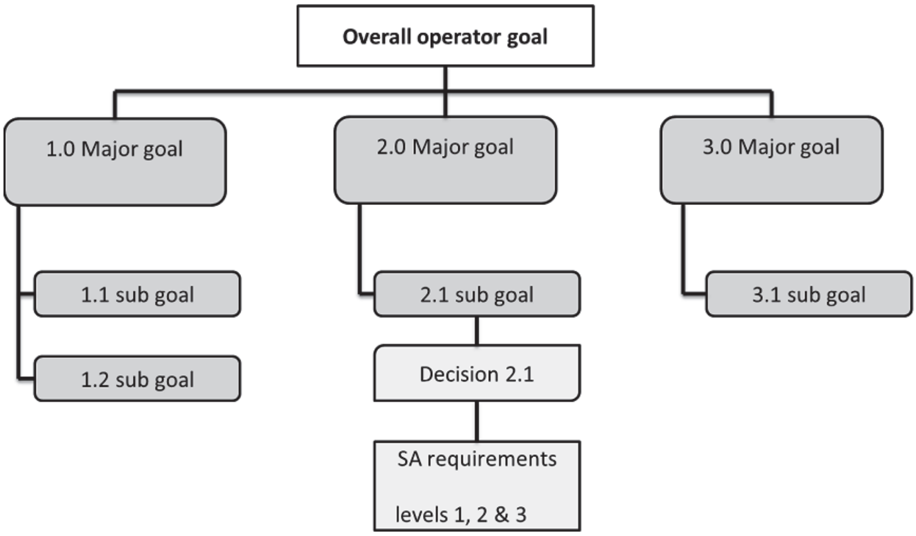

Figure 10 - GDTA hierarchy

3.3 Situation awareness global assessment technique

SAGAT [102] is rated as an objective measurement and it is well aligned with Endsley's three-level model. SAGAT is a freeze-probe technique focusing on stopping the running scenario for a brief moment and the subject matter expert (SME) is requested to fill out questionnaires concerning the current situation. Results are then compared to the known situation and points are given based on the answers. [125] Therefore, using SAGAT it is possible to obtain the level of the SA of the individual at a given moment. In this research, the SAGAT method [102] was used to evaluate the level of objective SA obtainable from the system user interface and in the definition of used services in the selected use case (see section 4.2 and publication VIII). SAGAT is designed to assess the participants' SA in terms of the three-level model (perception, comprehension, and projection).

SAGAT is a freeze-probe technique, which, according to Salmon [133], is the most commonly used SA measurement technique. The two main advantages with the freeze-probe approach are direct measurement of the operators, which removes the issues with post-trial and subjective SA collection. Secondly, SAGAT is a widely used technique, so it is a proven method. SART and SAGAT are the most validated methods in the field of SA. [133]

The critique of freeze-probe techniques reveals the need to be intrusive to the task performance and the techniques can only be performed when a simulation for the specific use case is under examination. The role of memory might also have an effect on the reflected SA results. [133]

3.4 Situational awareness rating technique

Situational Awareness Rating Technique (SART) is a post-trial subjective measurement method developed by Taylor [121]. It is a well-known and widely used technique. It is based on questionnaires provided to the SMEs. The method was initially developed for the assessment needs of aircraft pilots. SART takes a multi-dimensional approach, which comprises the level of SA required for the situation and the resources available. It is a self-rating technique, which uses ten-dimensional scales in which each object is rated from 1 to 10 in order to gain a subjective measure of SA. The original SART uses a ten-dimensional scale to measure SA. An example of a set of SART questions is given in Figure 11. [121, 125]

The questions in SART are divided into three different classes: the amount of demand on operators' resources (D), supply on operators' resources (S), and understanding (U). The level of SA can be calculated with the equation SA(calc) = U -(D - S). [20, 127]

The main advantages of SART is that it is easy to use and can be used in a variety of different task types. It is also usable in real-world scenarios and does not present the need for simulation. The downsides of SART include errors in defining one's own SA (e.g., what do I do not know?), the influence of operators' performance on the rating, and the effect of workload on the evaluation. [127, 134, 135]

An example of SART is given by Strybel et al. where they performed SA tests in the flight controller environment and received a rather surprising result of significant relation of SART scores when estimating the distance to a vehicle [136]. Liu et al. [137] present a combined SA model for use in a flight deck. They applied SART and eye-tracking methods to measure the results [137]. Drivers' SA has been examined by Beukel and Voort [138] using SART and SAGAT in a simulator situation.

SITUATION AWARENESS RATING TECHNIQUE

Instability of Situation

How changeable is the situation? Is the highly unstable and likely to change suddenly (High) or is it very stable and straightforward (Low)?

1 2 3 4 5 6 7

Complexity of Situation

How complicated is the situation? Is it complex with many irrelevant components (High) or is it simple and straightforward (Low)?

1 2 3 4 5 6 7

Variability of the Situation

How amny variables are changing within the situation? Are there a large number of factors varying (High) or are there very few variables changing (Low)?

1 2 3 4 5 6 7

Instability of Situation

How changeable is the situation? Is the highly unstable and likely to change suddenly (High) or is it very stable and straightforward (Low)?

1 2 3 4 5 6 7

Arousal

How aroused you are in the situation? Are you alert and ready for activity (High) or du you have a low degree of alertness (Low)?

1 2 3 4 5 6 7

Concentration of Attention

How much are you concentrating on the situation? Are you concentrating on many aspects of the situation (High) or focused on only one (Low)?

1 2 3 4 5 6 7

Division of Attention

How much is your attention divided in the situation? Are you concentrating on many aspects of the situation (High) of focused on only one (Low)?

1 2 3 4 5 6 7

Spare Mental Capacity

How much mental capacity do you have to spare in the situation? Do you have sufficient to attend to many variables (High) or nothing to spare at all (Low)?

1 2 3 4 5 6 7

Information Quantity

How much information have you gained about the situation? Have you resolved and understood a great deal of knowledge (High) or very little (Low)?

1 2 3 4 5 6 7

Familiarity of the situation

How familiar are you with the situation? Do you have a great deal of relevant experience (High) or is it a new situation (Low)?

1 2 3 4 5 6 7

Figure 11 - SART query [121]

3.5 System usability scale

The System Usability Scale (SUS) is a 10-point survey developed by John Brooke in 1986 to evaluate the usability of a system [122]. It focuses on estimating the usability of systems by simple means and provides an easy-to-compare scale of results from 0 to 100. The global average for SUS is 68 [139]. It aims to provide a low-cost method for broad usage. Usability can be hard to define since it depends upon the perspective of the observer. Brooke has defined it as "The appropriateness to a purpose." This brings the context of use and the user into central roles. In
Figure 12, the SUS query is presented. [122]

The calculation of the final SUS result is done by first calculating the score contribution for each statement. The odd-numbered statements (1, 3, 5, 7, 9) of the score are the number of the scale column minus 1. The even numbers (2, 4, 6, 8, 10) is the score equal to minus 5 from the corresponding column. Once all the values have been calculated, the result is divided by 2.5, which will produce the result. [140]

SUS is an inexpensive and fast way of determining the usability of a system. The actual test is easy to perform and does not require special skills of the administrator. It is also a technologically agnostic solution providing a quick and simple result in scores. The downsides of SUS are the possible calculation errors and misinterpreting the results as a percentage. SUS is also not capable of creating evaluations of a single change or component in the UI. It does not pinpoint the issues one might have in the UI, and in that case, a further examination is needed. [140]

1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

Figure 12 - SUS query [122]

3.6 Eye movement tracking

Eye movement tracking refers to the process of measuring where the eye is focused and to the eye motion in the area of sight. When in use, the system is able to determine quantities, for example, in the following areas:

- Where the SMEs are looking
- How long they are looking
- What is the focus from item to item
- What parts of the interface are missed
- How the placement of items affects the attention [141]

Eye tracing is usually not the first step in the usability study and Pernice and Nielsen suggest performing comprehensive traditional tests prior to eye tracking, as they are cheaper and simpler [142].

Eye tracking can tell where and when the attention is directed. Moreover, the method is able to differentiate if the user is reading or scanning the content. It also enables the possibility of comparing the behavior of different user groups (training, education, history, etc.) in order to identify the differences. The limitations include the reliability; it cannot be stated whether an object, which has been seen, is actually processed. It also does not tell why users are looking at a particular element. In terms of SA, the test does not conclude how the gained information is being used and fused. [20, 141]

3.7 Comparison of the methods

As SA is an internal mental construct, the results of different methods might prove hard to compare. In addition, extensive empirical testing of different methods would require a reliable baseline for each method. The methods can be divided into four distinct groups by approach: process measures, direct measures, behavioral methods, and performance measures. These methods have their unique characteristics and they reveal only a portion of the whole SA. This often leads to situations where the methods are used in combinations. The used methods are described in Table 9 and methods bound to the measured components are presented in Figure 13.

The methods can be further divided into subjective and objective. In subjective methods, the procedure is to ask the operator or expert observer about the level of SA over a specific time. This is done by presenting questionnaires as simple as scaling from 1 to 5 or in a more complex fashion. The result is later organized to describe SA in a given period. Subject measures are simple to perform, being inexpensive and non-intrusive but may lack in accuracy. The drawbacks to subjective methods include questions of whether you know what you do not know, the observer does not know what the SME knows, the SME might be tainted by performance outcomes, and having too much confidence in one's own SA. [20]

Objective methods by contrast focus on comparing the operator's reported SA to reality. This is usually done by asking the operator about specific events/items in the environment and then assessing the speed and accuracy of the responses. This will then deliver a SA status for a given moment but does not represent the whole SA in the scenario. The policy will be able to compare and assess SA in terms of the reality but presents a set of challenges such as timing, stress factors, right questions, etc. The downsides are that the methods capture SA at the end of an exercise and memories might not be reliable (post-test). In SAGAT, the freezing of the situation might have an effect on one's SA and flow of the mission [20].

Method	SAGAT [97]	SART [121]	Eye Tracking	SA Requirements Analysis [98]	Performance Measures (Various)
Type	Freeze- probe recall technique	Self-rating technique	Process indice	SA requirements analysis technique	Performance measure
Origin	Aviation	Aviation	Generic	Generic	Generic
Individual/team	Individual	Individual	Individual	Individual and team	Individual and team
Training time	Low	Low	Med	Med	Low
Tools	Task & System Simulation Computer	Pen & Paper	Eye Tracker equipment and software	Pen & Paper Audio recording device	Dependent upon task under analysis
Strengths	- Direct approach - Extremely popular approach that has been subject to numerous validation studies - Removes problems associated with collecting SA data post-trial	- Quick, low cost and easy to use requiring little training - Generic, can be used in other domains - Non-intrusive to primary task performance and can be used during real-world SA assessments	- Relatively non-intrusive to primary task performance - Can be used to determine which environmental elements are attended to - Widely used	- The output specifies the elements that comprise operator SA in the scenario under analysis - Output can be used to develop SA measure - The procedure is generic and can be applied in any domain	- Data collection is simple - Provides an objective measure of SA - Non-intrusive and can be applied during real-world collaborative SA assessments
Weakness	- Requires task and system simulation - Intrusive to primary task performance and may direct attention to SA elements - Cannot be applied during collaborative real-world tasks	- Problems of gathering SA data post-trial, e.g., correlation with performance, forgetting low SA periods - Issues regarding sensitivity of the technique - Has not performed well in various validation studies and it is questionable whether it is in fact assessing SA	- Equipment is temperamental and difficult to operate, cannot be used "in-the-field" and the data analysis procedure is very time consuming. - "Look but do not see" phenomenon should be considered - Offers only an indirect assessment of SA	- The procedure is time consuming, involving observation, interviews, and task analysis. - Access to numerous SMEs is required for a lengthy period of time. This may prove difficult to gain -Describes only the SA elements and not the interactions between them	- The relationship between performance and SA is an ambiguous one, e.g., poor performance can still occur even when operators have poor levels of SA - Indirect assessment of SA - Suffers from diagnosticity and sensitivity problems.

Table 9 - SA measurement techniques adopted from [94]

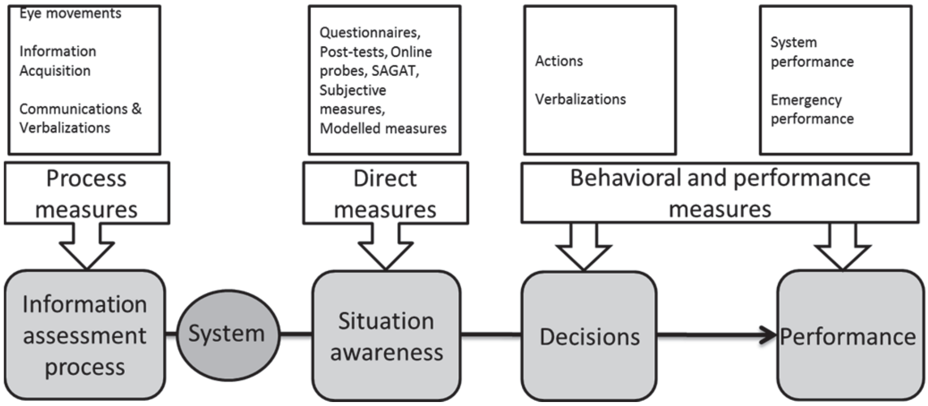

Figure 13 - SA measurement adopted from [20, 143, 144]

During the project, the different SA methods were evaluated and the correlation to SUS, SAGAT, SART, and performance were calculated. These results can be found in P VIII, Tables 4, 5, and 6.

4

TEST PLATFORMS

This chapter will present the systems used to empirically examine the created concepts. The fundamental blocks are the two systems: the Mobile Urban Area Situation Awareness system (MUSAS) P [III] & [IV] and Situation Awareness of Critical Infrastructure and Networks system (SACIN) P [V] & [VIII]. These two environments respond to different use cases but have a large number of unifying features and also the bounding purpose of creating sufficient situation awareness (SA) for the operator in order to achieve the goals for the mission.

4.1 Mobile urban situational awareness system

The Mobile Urban Situational Awareness System (MUSAS) was made to improve the SA of the dismounted troops in an urban area. The main duties of the system include the creation, gathering, and sharing of the common operating picture (COP). The background is in the "Wireless sensor systems in indoor situation modelling (WISM II)" – project [145]. During the project, a short video was made to highlight the main aspects of the created concept and implementation of the system [146]. The demonstration environment was tested in a session where craftsmen used and tested the system.

4.1.1 Concept

MUSAS is by nature an independent system. It is designed to operate in isolated conditions, and it is able to form and support internal connectivity and services. The system has the ability to communicate and update from external systems in case connectivity and services are available. In this context, some real-world requirements have been placed outside the scope of the research, such as battery capacity and extreme durability. The main goal is to test and evaluate the concept of an independent solution creating a COP independently. At the same time, the system is built using commercial-off-the-shelf (COTS) technology. This enables rapid deployment of new devices to the system.

Highlights of the system include the following:

- Ability to create and maintain multi-level network infrastructure
- Ability to form maps and objects using sensor networks and simultaneous location and mapping technologies (SLAM)
- Ability to deliver the information to operative users by means of a mobile ad hoc (MANET) solution
- Blue force tracking capability
- Rapid deployment of new end user devices
- Information fusion of heterogeneous information sources
- Possibility to share the COP outside of the system

The high-level components are shown in Figure 14. The focal component is the Common Operational Picture Server, which contains the COP model. The COP model contains, for example, state and location of objects, mission, and status information. Based on this model, the information is drawn on top of maps in the actual devices. Different kinds of localization systems can be connected to the server (blue force, enemy detection, drone location and image, SLAM maps, etc.), depending on the needs. As the fusion process becomes ready, the information is shared with the users via the operative sharing component, which consists of ad hoc protocols and network devices.

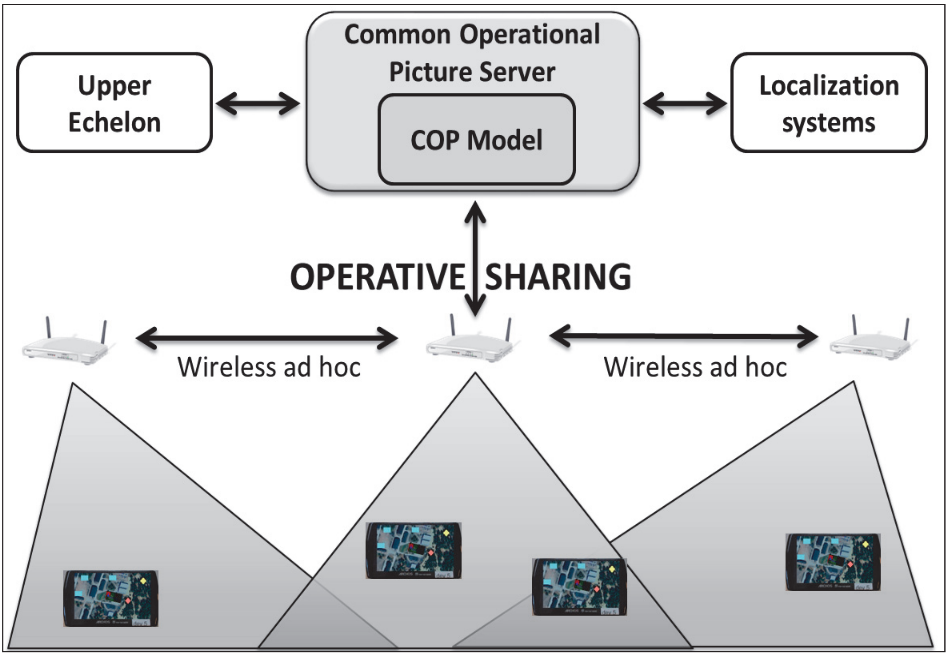

Figure 14 - Information sharing

Core tasks in the system consist of designing and implementing the information fusion and providing the COP to the operating entities. The system consists of multiple heterogeneous information sources, which need to be formalized and fused in order to provide a set of unified data for the users. The system-level component structure is described in Figure 15. The three distinct entities that are implemented are mapping, target localization, and team localization. These components provide the raw data for the COP server, which is the component responsible for the information fusion. Backdrop information contains items such as based maps and mission information. This information is fused with the COP model and provided to the users via the operational sharing component.

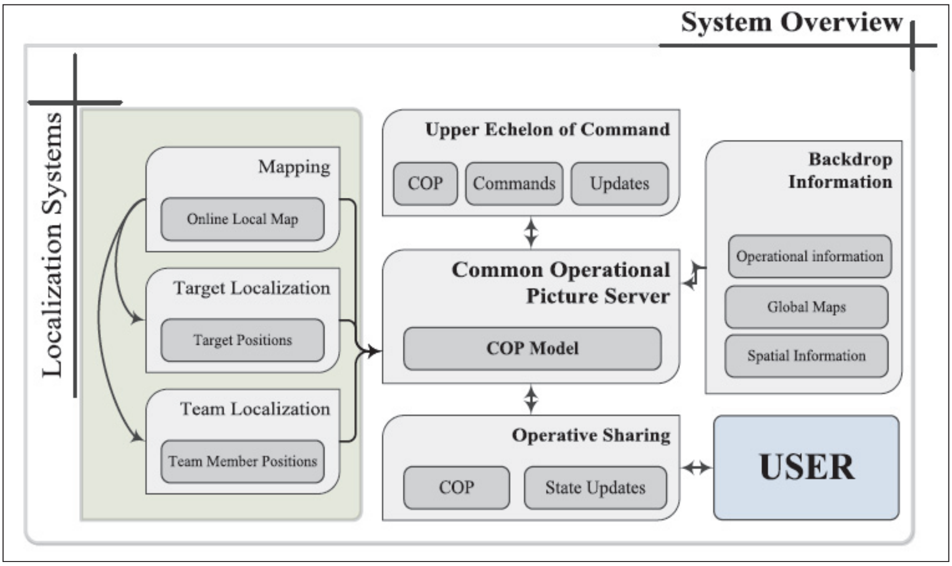

Figure 15 - System overview P [IV]

4.1.2 Implementation

From the perspective of implementation, an important component is the middleware connecting all of the components. In this project, we used an Internet Communications Engine framework (Ice) [147]. The Ice framework enables cross-platform communication and is an open source product. It supports multiple programming languages, such as Java, C#, and C++, which were used in this project. The approach is to use the IceStorm server, which provides an object-oriented approach based on topics where clients can publish and subscribe. These topics are used to support communication from the different sensor entities toward the information integration component. The Ice middleware combined with the servers' system (see Figure 16) forms the core, which enables the rapid deployment of new sensor systems to the architecture.

In this project, the implemented sensor systems from a functional perspective are as follows (Figure 16):

- Wearable sensor node
  - Blue Force Tracing (BFT) [148]
  - Communication via dedicated MANET network at 2.4 GHz frequency
- Wireless Sensor Platform (WSP) [149]
  - Through-wall imaging [150, 151]
  - Communication via dedicated MANET network at 2.4 GHz frequency. This network was used to deliver a variety of information
- Robot performing SLAM [152]
  - Uses WSP platform, 3G and WiFi to communicate (contains a multichannel router)

- Stereo vision with cameras
    - Laser for accurate creation of blueprints
    - Ability to accurately locate own location [153]
- Operative sharing
    - Creates a 5 GHz MANET network using WPA authentication (see Figure 14)
    - Connects end user devices to the server system
    - Enables GPS-based location sharing in addition to BFT subsystem
    - Presents COP to the end user
- Upper echelon
    - Enables two-way communication using the Ice interface
    - Enables low bandwidth operation where only simplified status/location is transferred
    - Gateway type can be, e.g., VHF, WiFi, 3G, other tactical networks, etc.

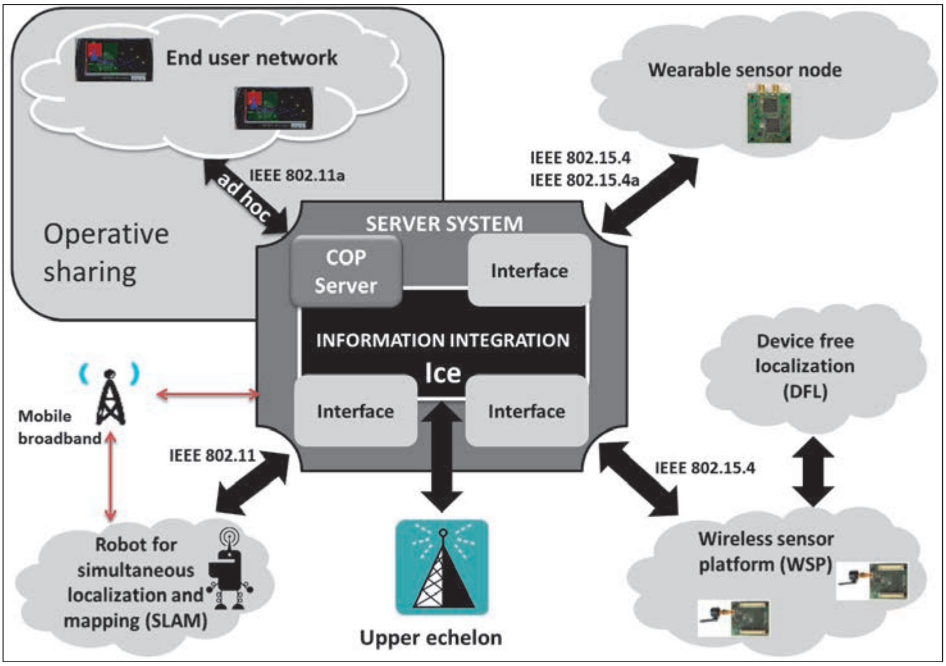

Figure 16 - Implemented architecture P [III]

The components inside the COP server (see Figure 17 above) are presented in greater detail in Figure 17. The COP server divides the presented items into two categories based on the type of information. The COP model logically contains these categories, but its functionalities are more focused on maintaining entities that have a changing state. The COP model delivers the updates via the localized objects from which the actual COP is being drawn in the devices. Backdrop information contains static entities, such as maps, building blueprints, and mission graphics. From the perspective of implementation, this results in two separate server functions for each. The servers used are the Esri tracking server [154] for moving and constantly updating targets and Esri ArcGIS server [155] for static targets. Command and control (C2) application is located at the center of Figure 17, but it also connects to the system services using Ice middleware. This application has more features compared to the end user device. An example of this would be the ability to receive the laser-beamed blueprint created by the robot (see Figure 19 where the SLAM map is placed on top of a map).

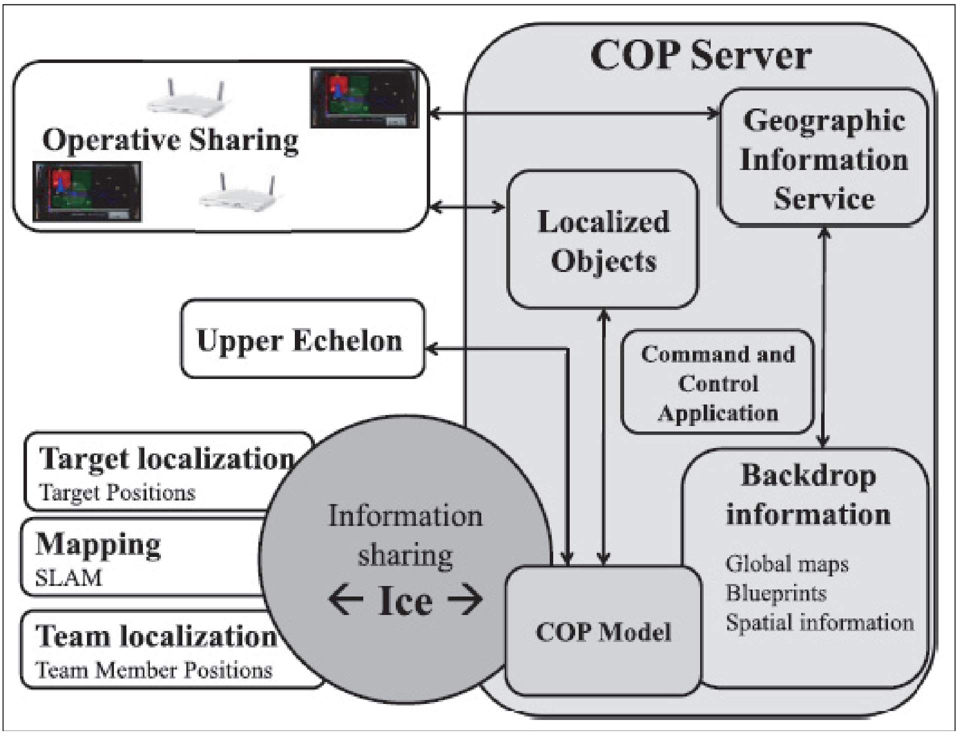

Figure 17 - Fusion architecture P [IV]

The result of the process in wide view angle is shown in Figure 18. This view is from the C2 application, which is used from a laptop computer during a test session. In this version, the development options are visible so it is possible to see the traffic through the Ice server. At the top left corner the user can see the coordinates of the mouse pointer in different forms. From the top center dialog, it is possible to add new objects to the map, which will be automatically updated to the mobile devices.

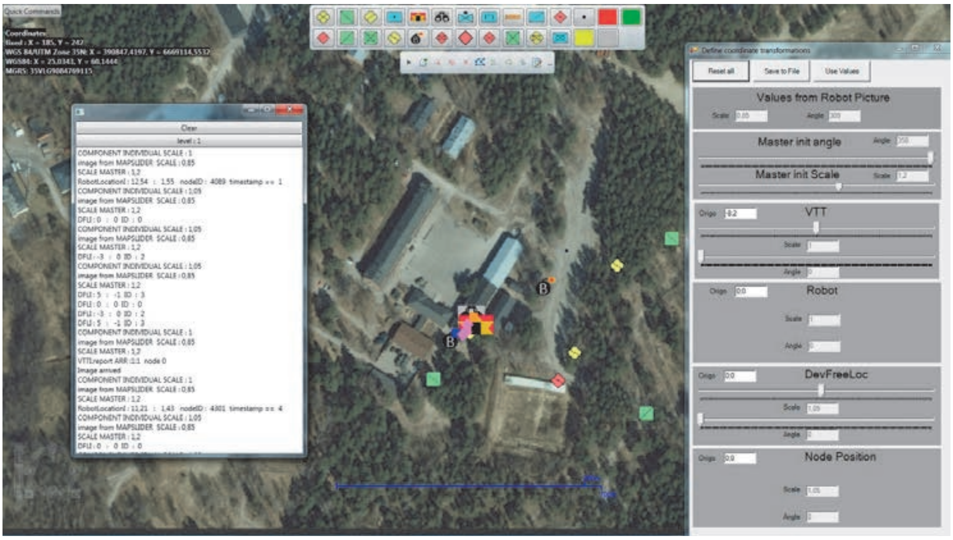

Figure 18 - General view

The detailed view inside the same building as depicted in the previous picture is presented in Figure 19. In this view, it is possible to see the interior of the building where the normal map is fused with the objects in the system. The map formed by the robot using SLAM is illustrated with light gray. From this information, the shapes of the rooms are being drawn and sent to the end user devices. The location of the robot is in the center of the screen (an orange rectangular shape). A blue force object is in the first room from the left depicted in the color blue. The base color of the rooms describes the status of the room (green = safe, yellow = unknown, red = dangerous). The system was not designed to meet the requirements in terms of color blindness of the users.

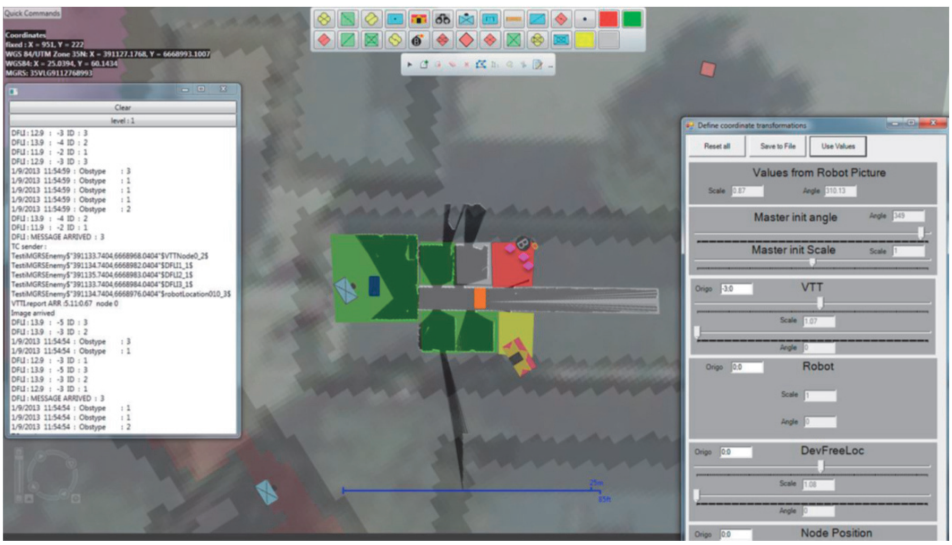

Figure 19 - C2 application P [IV]

The same situation after a brief moment is described in Figure 20. In this picture, the locations of moving targets are not depicted, but the application normally displays them as in the picture above. The mobile application is extremely simple and the user does not need to use the device during the action. The user can zoom, twist the screen, or add objects to the map. The network would support sending a video stream or voice messages, but these features were not implemented.

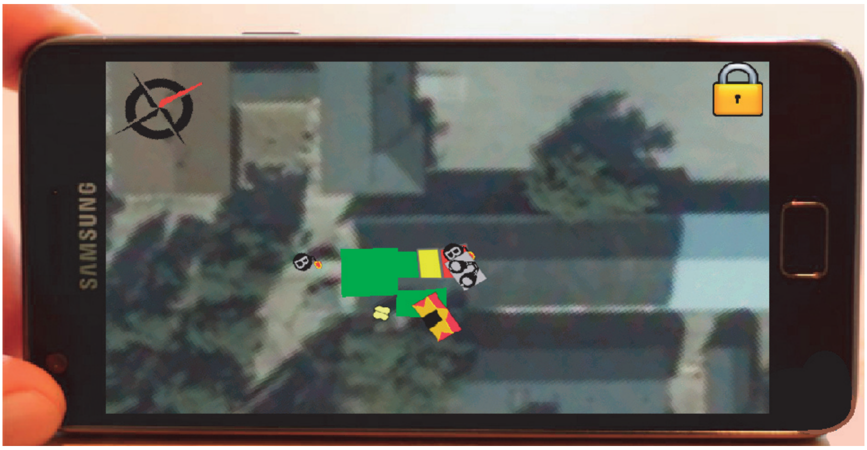

Figure 20 - Soldier's display P [III]

4.1.3 MUSAS tests and results

The system was placed in a field test in an environment specifically designed for training of urban area warfare. In this test (see P [III] & [IV]), the full system previously presented saw action where the users were conscripts with no special technical knowledge. The unit specializes in urban area operations so the tactical level is very familiar to them. The scenario contained a target unit simulating an adversary inside the building commencing an active hostage situation. The final event was also a public event for the contributors to see the results. The focus was not solely on system/component testing but on final integration and usability tests as well as presentation. The experiment was performed in a testing facility, mainly consisting of a plywood maze for training troops in urban area warfare. In the tests, a platoon-sized unit, specialized in urban area warfare, faced a hostage situation in an environment, which was unknown to the unit. The unit used the equipment provided by MUSAS to determine the shape of the building and the location of targets.

The tests proved that sensor-based systems, as well as information-sharing networks, are able to operate in this sort of environment within the scope of the research. The event produced multiple improvements in terms of integration, radio frequencies, update frequency, and usability. A notable result was also the final placement of the mobile device, which was first designed to be used on the wrist area, was now placed to the chest area in the upper torso. [III] & [IV]

During this testing session, no SA measurements were performed. Rather, the users reported feedback and comments from using the system. One of the main requirements was to provide knowledge for the troops that are the main targets within two rooms of range, which was achieved. In addition, the demonstration evaluated ways of improving the tempo and survivability. Moreover, based on the interviews, the usability and simplicity was evaluated as good. The only criticism was toward adding the targets from a mobile device and focused on discussing whether the operator has the time or possibility for such an activity. The recommendation was to move the used device to the patrol leader's responsibility, as he/she is the first person who is able to look at the display and use it. The first line warriors would also carry a device but the screen would be blank according to the role-based view P [I].

4.2 Situational awareness of critical infrastructure and networks system

In the domain of CPS environments and critical infrastructure (CI), the concept system is called the Situational Awareness of Critical Infrastructure and Networks (SACIN) system. SACIN has been under active study in the Finnish National Defence University. The results include the concept of operations when protecting a highly interconnected society, especially from the perspective of the operators and decision makers. The system focuses on delivering the right information to the right person at the right time. Moreover, the solution delivers a large-scale picture of the highly interconnected and heterogeneous functions of society. P [VI] & [VIII] The information flow in the concept is depicted in Figure 21. The most important components from the system's perspective in the loop are Source systems, SACIN framework, and decision makers. The actions, events, and COP will circulate between these actors, and the reason for SACIN to exist is to enable this communication in a meaningful manner.

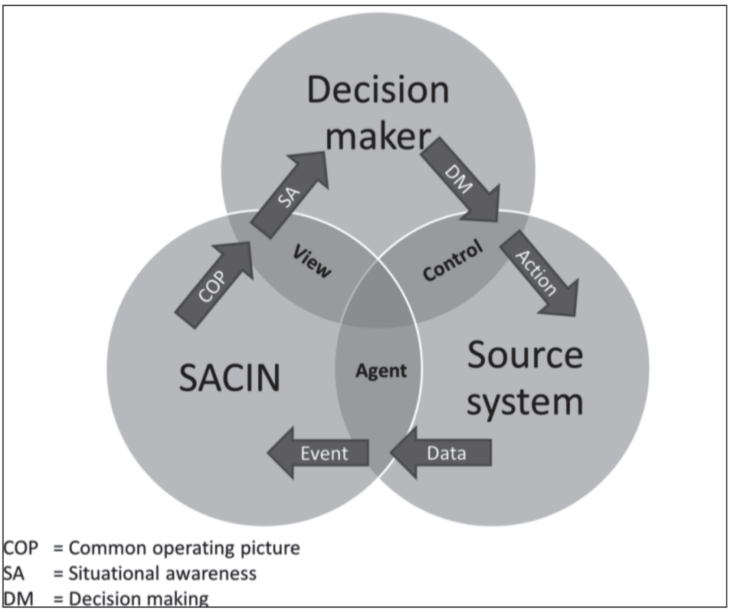

Figure 21 - SACIN information flow P [VI]

4.2.1 Concept

From the elements of CI, the companies are the most important information source for the system. In this context, we refer to them as *source systems*. The main source of knowledge is from the subject matter experts (SME) working in the companies. These SMEs, who have specific knowledge about their operational environment and systems, are referred to in this research as *source system operators*. Through source system operators, the business case of SACIN is to support the systems in CI by providing simplified vital information about the society. This includes humans in the loop for creating more accurate information to the system. The COP is then presented to the source system operator who is able to guide, understand, and predict processes inside the company in a more accurate manner.

The preliminary decisions on system structure and use include, for example:

- Agent-based approach to end user networks and system
- Use of existing network solutions
- Abstraction of information – no need to transport all information to the system
- Limiting the amount of information based on logic in the sending component
- Adding value and responsibility to the source systems using the system

In order for the users to understand one another in a similar manner, a model for describing the dependencies and connections in CI was taken into use. The model is created by Ted Lewis [156] and complemented with event ratings [157] and categories [158]. The taxonomy of CI is presented in Figure 22.

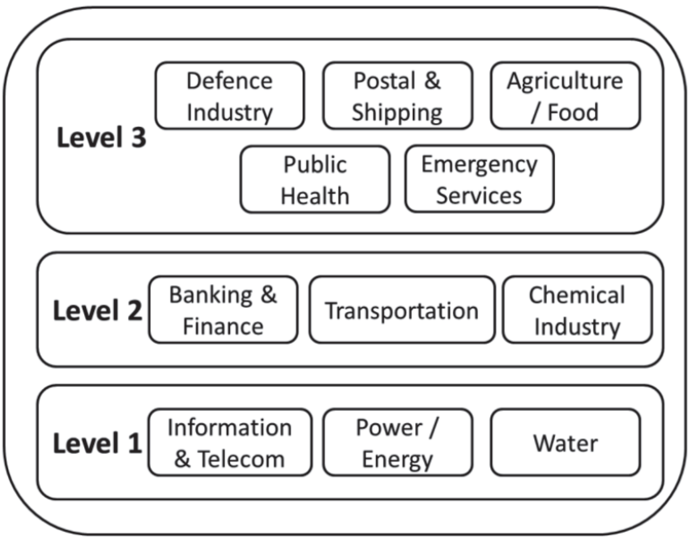

Figure 22 - CI based Ted Lewis (modified) [156]

The actual operation of the concept system is described in Figure 23. The loop begins from the CI where source systems represent the companies building critical services or products. In these companies, the most important person in terms of SACIN is the source system operator, who is responsible for the process and can have an effect on decision making in that particular source system. The agent component will be installed here and the data is sent to the SACIN framework. In this framework, there are agents, which are either human controlled (operator in Figure 23) or automated (analyzer in Figure 23). An example of an analyzer component for this purpose is the SHODAN-based SCADA scanner described in [159]. Supplementing agent components by analyzers and operators will result in an in-depth analysis of the information but, from the system perspective, they operate as agents. Based on this information, the COP of CI will be formed and presented to the right instances. In terms of the authorities at different levels, it is possible to use information to one's own purposes. The SACIN system does not present a gateway for decision making and delivering those decisions to further participants. The purpose is to build sufficient SA of national CI in order to understand the situation and relations in a general way. Based on the information, the decisions can be made and delivered by the means available, such as telephone, email, and other systems. The COP of CI is also presented to the companies contributing to the system in a simplified manner. This information is meant for internal improvement of the processes and decision-making capability. Often the case is that the only real decision-making power is inside the company and the authorities' only possible gateway is to support the companies of CI by estimates, service agreements, and COP.

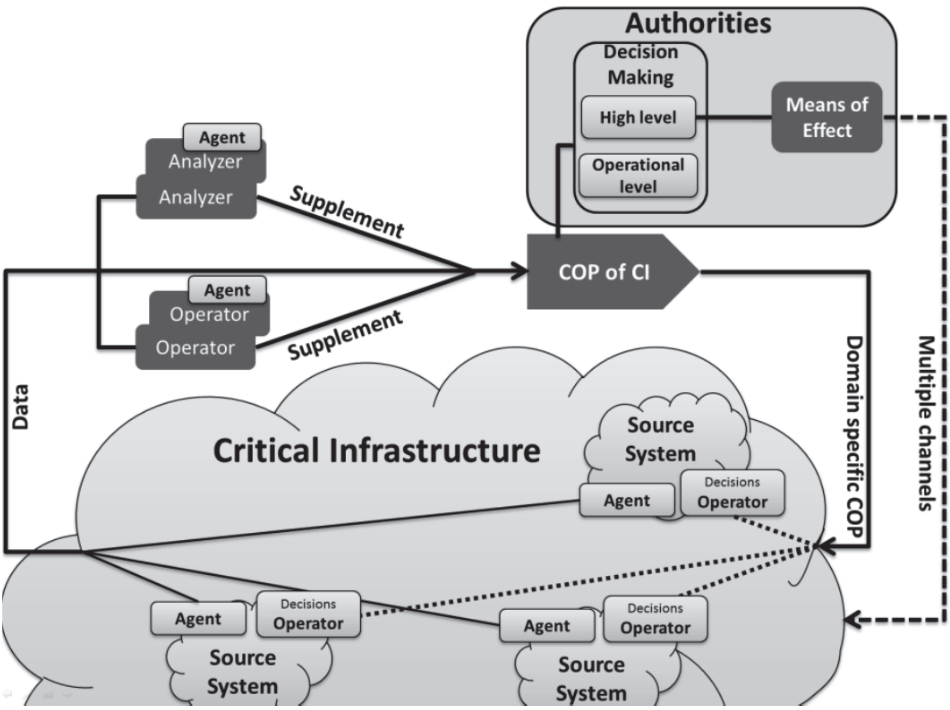

Figure 23 - Concept of operation P [V]

In this concept, automation obviously plays a big role. The issues of big data are quickly in the hands of researchers as the system grows; even the agent component is involved in the preliminary cleaning of information. It is clear that human interaction is required in many cases in addition to computer intelligence. In Figure 24, the human operators are also presented.

The role of human intelligence is recognized at least in the following points:

- Source system SMEs
- Operators acting as agents in the system
- SA monitor room operators (industry branch, geographic area, etc.)
- Decision-making-level authorities

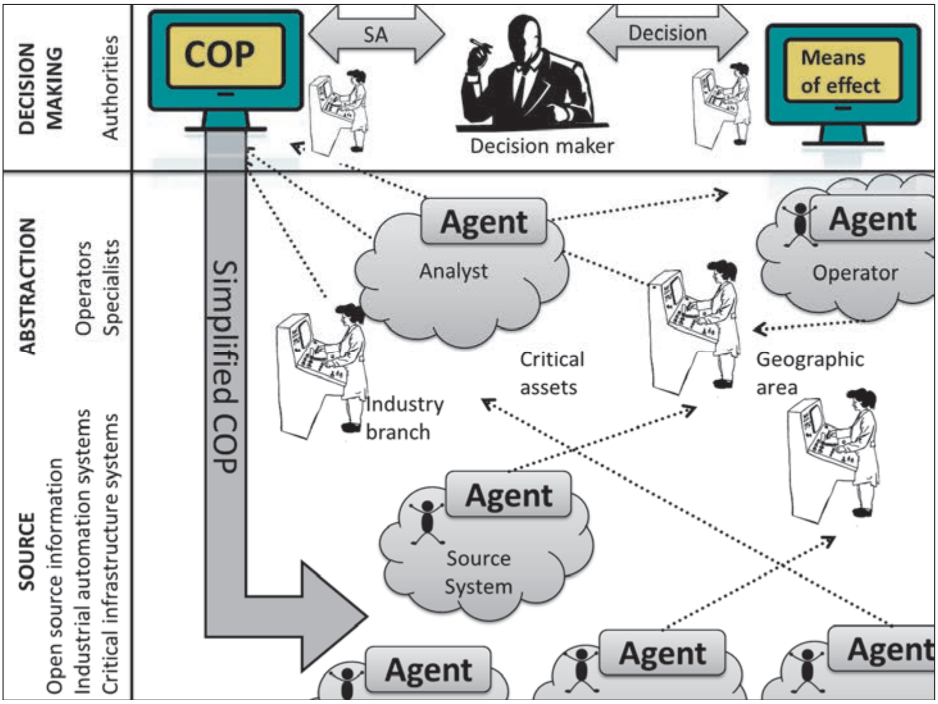

Figure 24 - Behavior

4.2.2 Implementation

As mentioned earlier, the implementation relies on JDL model architecture and divides its components accordingly. The implementation uses a message bus solution and relies on an information stream solution where each component will follow the information being sent. In Figure 25, the components are presented in accordance with the JDL model. The agent is located at level 0 as it basically modifies the information so that it can be understood by the SACIN. It is also the only component located at the source system. The core services contain the rest of the JDL levels and object, state, and impact are actual components implemented to the layers.

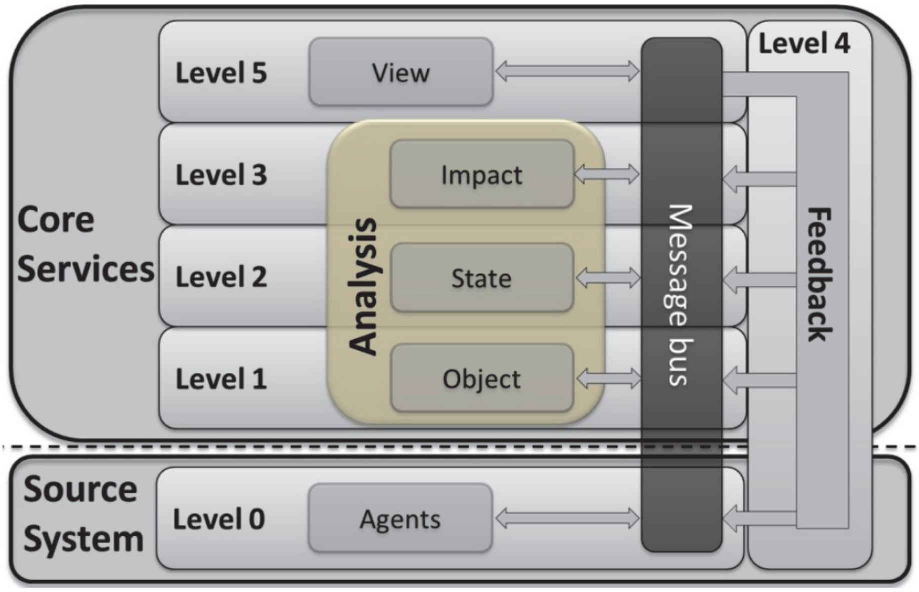

Figure 25 - JDL implementation P [V]

The system is distributed by the components at the core services level. The services are able to interact via the message bus but are not necessarily in the same physical entity. The architectural solution is called brokered architecture. P [V]

A crucial component for the entire system is the agent. It has been implemented to be self-sufficient and to provide all the messaging capabilities to the SACIN so that the source system is completely free in implementing the messaging features and formats. The agent is an instance of plugin architecture where the source system is capable of connecting via the designated interface to the agent. A natural place for the agent to be installed is the control facility of the source system where all meaningful information is being gathered as a matter of course. The source system operator is responsible for defining the importance and effectiveness of certain events to the plugin, as in the SACIN framework it is impossible to evaluate the importance of events. This work can be seen as a baseline creation, after which the system is able to operate in a more independent manner. The relations of the agent are depicted in Figure 26.

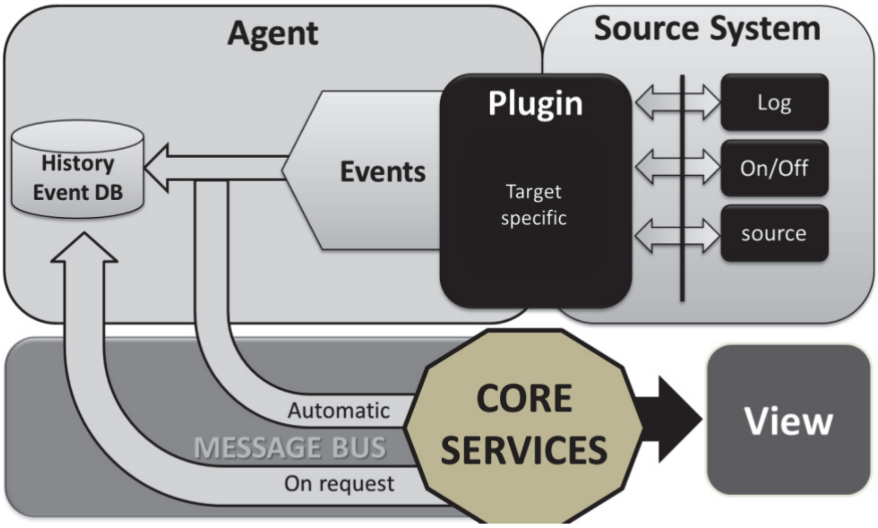

Figure 26 - Agent architecture P [V]

The final result of the architecture is naturally the view component P [VII], which actually delivers the created COP to the users and so builds up the SA. The UI is shown in Figure 27. The system consists of four different views for the user, which are interconnected and interact with one another:

1. Selection screen (leftmost)
   - The purpose of this screen is to present quickly the incoming event using the CI taxonomy. It presents the categories, severities, and classification of incoming events. From this menu the operator is able to select which component will be followed. By clicking the circles, the registered agents can be seen and selected to be followed.
2. Temporal screen (center, bottom)
   - This screen will present the incoming events as a feed (only the selected feed from screen 1), which can be marked as noted. The screen also contains a timeline where the incoming events are organized. This screen was recognized as the most valuable screen by the users in the test. P [V]
3. Relation screen (center, top)
   - The purpose of this screen is to present the relations and dependencies of the selected components from screen 1. This screen is able to present relations, for example, networking services in a hospital bound to the electricity company.
4. Geospatial display
   - This screen is a traditional map representation of events and selected components. As the operator clicks any object on other screens, the map locates the target for the operator.

Figure 27 - Sacin UI P [V]

4.2.3 SACIN tests and results

The system has been developed based on the concept discussed in previous sections and tested by the target users. For example, the system UI has undergone a series of tests and improvement cycles. P [VII] The concept as well as the system has been presented in seminars and workshops as well as amongst the actors in CI, especially in Finland, in order to evaluate the suitability and rationality of the product. At the implementation level, JDL levels 2 and 3 present the most challenging features including prediction. These features are partially implemented and the research to solve specific issues is continuing. P [VIII]

For the SACIN system, the GDTA and SAGAT tests have been conducted in order to evaluate the usability of the system as well as the level of SA of the operators using the system. P [VI] Interviews from 12 people from different sectors were conducted. These interviews covered seven out of eleven sectors of CI, defined by Ted Lewis in [156]. In addition, an SUS test was also conducted, resulting in a score of 71 (global average 68), which is a good result for a system of this maturity. The results of the experiments are presented in publications VI and VII.

The two distinct blocks discovered in this research were the incident-related information and system-related information. Rummukainen has divided these blocks into specific tasks by using Endsley's model. This division presents the most important foundations of situation awareness in our scenario. The results of GDTA analysis for CI monitoring are shown in Figure 28.

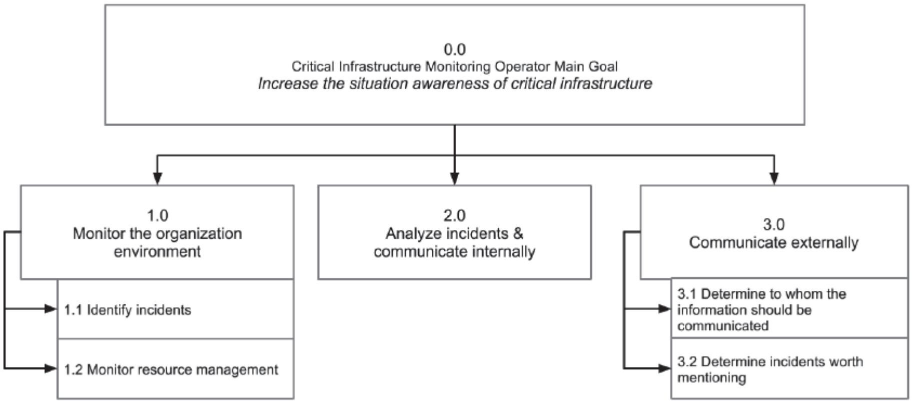

Figure 28 - GDTA of SACIN [VII]

As anticipated, the goals and SA requirements are focused on information and in the use of information. A surprise was that the main task of the operator is to act as an information mediator and share the information with those in need of it. The decision-making is related more to deciding what information to share, not to actual decision making.

4.3 Situation awareness in the different environments

The environment is vastly different, but it seems that in terms of SA, there are multiple connecting points on both of the cases. In addition, the use of the senses is different in the environments. GDTA provides a tool to evaluate the differences and similarities in the goals.

It is probably self-evident that these environments have many differences in the field. The most dramatic difference in the environment is the fact that an imminent life threat exists for the dismounted forces. The type of decision making is also different as the dismounted leader focuses on addressing the most crucial decisions during the action and he or she also makes the final decision based on the level of freedom available (mission tactics). Moreover, the mission in dismounted circumstances is highly focused on the geographical location, which is perceived completely differently in the monitor room since the mission area is usually logical.

In terms of stress and pressure, both environments have their specific factors. While in dismounted operations, the physical stress can be high, that is usually not the case in the monitor room environment. Still, the mental pressure might be extremely high in both of the cases and when combined with prolonged operations with inadequate amounts of sleep, the combination can be very stressful.

The effect on others has a different approach in these cases. Dismounted operations are internally interconnected by nature. Their building blocks are combined movement and split tasking, which enables the movement of the whole troop. On the contrary, the monitoring room operator is usually handling large entities where failure might damage the C2 connections of the entities using the systems. This can bring additional stress to the operator's work depending on the goal.

The use of the senses is naturally different, but the dominant sense stays the same. In both of the environments, vision is the key sense and the main source of information. In dismounted operations, a variety of senses are in constant use and those senses also contribute to SA. In the controlled environment of the operator, the uses of the senses are dramatically different. Depending on the UI, usually the operator's only sense in use is vision (there might be audio or vibration actuators). It probably depends on the active mission how many senses can be used as a feed in the monitor room environment. The tasks are boring by nature, so the need to deploy alarms using a variety of senses is fairly high, but these cannot be overwhelming for the operator.

In the focus of this research, GDTA has been performed on the SACIN system but MUSAS has not undergone the method. Some similar studies can be found where GDTA can be used to compare the results. Based on the results in the context of CI, the operator is focusing on operating as a mediator and not making specific decisions. This is a surprise to some degree. According to Rummukainen [160], the main tasks are in mediating the information and the main decisions are related to what will be shared and with whom the information is shared. The actual main goal is to build and maintain sufficient SA. Communication inside and outside the organization is an essential task. P [VI]

The platoon-level dismounted soldier is more task oriented and may actually make decisions that can have an imminent impact on the operation, as presented in [161]. All the goals are highly related to the actual mission and focus either on enabling success or shielding one's own troops. As the goals in dismounted forces do not include SA or communication as a task, it is likely that these processes are hidden inside the activity or taken as self-evident tasks. For example, a large part of the platoon's success is dependent on right-timed decisions based on the leader. This in turn builds a need to use a decision-making paradigm to constantly assess the situation and give orders at the right time. Giving orders is the natural way for a military group to communicate, also communicating to a higher echelon is also a regular duty in dismounted forces on the move. This would add up to dismounted forces also having the goals of internal and external communication and building SA.

In Table 10, the results of GDTA analysis are presented. It is easy to see that dismounted forces have more detailed goals, which are tightly bound to the mission itself. As in the cyber environment, the scope is wider as the operator might not even know what sort of situations are coming.

Monitor room P [VI]	**Dismounted** [161]
Increase the situation awareness of critical infrastructure Monitor the organization environment Analyze incidents & communicate internally Communicate externally	Avoid casualties Negate enemy threat Movement: Reach point X by time Y Assault through objective Hold objective Provide stability and support operations (SASO) Function in a team environment

Table 10 - GDTA comparison P [VIII]

4.4 Common service structure

It is not unusual that the user or operator does not know what are the actual situational awareness requirements enabling success in the current mission. For this purpose, the proposed architecture presents a service-based approach where the services are distributed and solutions for the end users are tailored using the existing service set. Moreover, the new implementations are based on goal-driven task analysis (GDTA) [20], from which the situational awareness requirements for the specific tasks can be discovered. The design follows the guidelines of user SA-oriented design, but also presents the division of services according to the SA levels, which makes sure that the user is taken into account when designing a new system. This approach is first presented by the author in [162] and continued in P [IX].

In this framework, the fundamental components are the following:

- Joint division on the laboratories (JDL) model of data fusion
- Three-level model of SA for dividing services by technical level
- GDTA analysis for discovering vital SA needs
- Service-based architecture for publishing and integrating the services

The combination of SA levels in terms of the JDL model is presented in Figure 8. This figure emphasizes the user's mental state, which is the only place where SA is being formed and stored. Naturally, in the monitor room environment, the main source of SA is the COP screens but it does not remove the importance of the operator's SA.

The Endsley's model of SA was first presented as a cognitive model but later used also in conjunction with the JDL model. Endsley has been critical of using the model for this purpose, as JDL is an engineering model not designed for human systems. [100, 163] In this research, the approach is technical and focuses on architectural solutions. Accordingly, it does not directly address the measured SA from individuals but rather the technical design of the system. The three-level model is used to separate the technical services from each other, not for purely cognitive purposes.

MUSAS and SACIN are both built with a service approach, but the environments and scope differ. MUSAS consists of multiple mesh networks providing sensor information as well as a network for operative sharing. As the information is coming through the unified message bus, the service-based approach is achieved. P[IV] A new system authenticated to any network can start sending information, which is available for all the entities attached to the message bus. These services could be divided as presented in this section and combined with the information from the upper echelon to further support the approach. In the case of SACIN, the structure contains a brokered architecture to which a service-based approach can be applied. P [V] Furthermore, as SACIN exists in a networked environment, existing services from the Internet can be leveraged to the use of the service-based approach and divided among the corresponding SA level at the SACIN level, leaving the original service intact. Examples of this type of services would be weather and authentication services.

In Figure 29, the common way of creating and organizing services is presented. Quite often, the services are divided into layers, such as strategic, operational, and tactical. This structure is used to coordinate the level and distribution of services. Here, a service-based architecture is being proposed where each layer is created independently and using a service-based approach where services can be independently built and then combined with other services. This approach is commonly used when implementing a service-oriented architecture (SOA) [41]. Furthermore, the architecture proposes using Endsley's three-level model when building the technical services for each level.

These levels can be described as follows:

- Strategic-level service structure
  - perception-level services joint services
  - comprehension-level services joint services
  - projection-level services joint services
- operational service structure
  - perception-level services
  - comprehension-level services
  - projection-level services
- Tactical-level service structure
  - perception-level services and networks
  - comprehension-level services and networks
  - projection-level services and networks

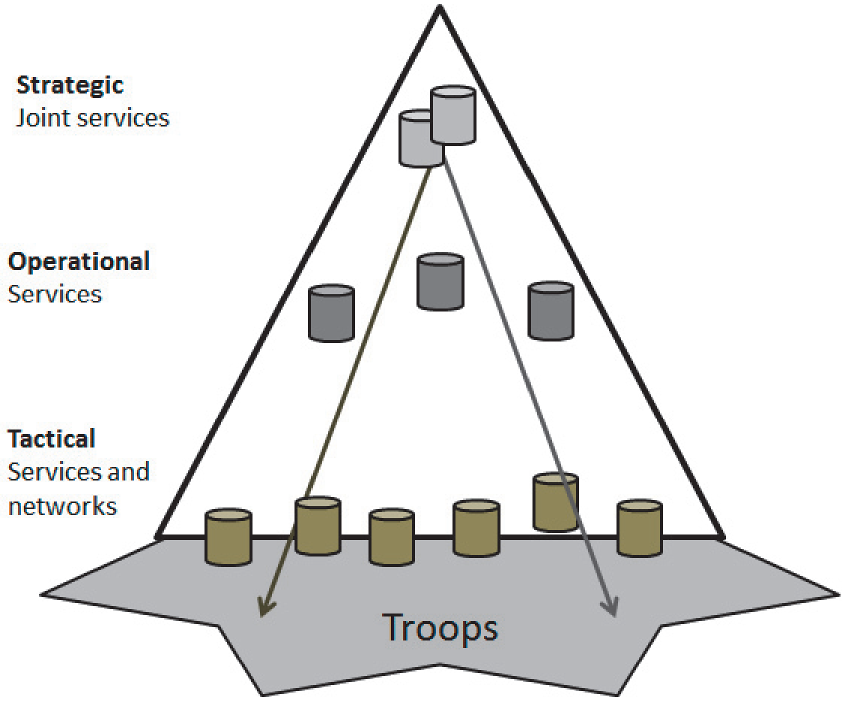

Figure 29 - Service structure

An example of this kind of service structure would be a service where precipitation is offered from multiple locations across the country as a strategic-level service, and based as a perception-level service. This information can be used and complemented with detailed measurements at the operational and tactical layer, for example in artillery positions. The service for the current weather would be a strategic service (comprehension level) and the weather forecast (projection level) is in the tactical layer but providing projection-level information. This information is possible to use in the tactical layer, for example when evaluating the transportation ability of the terrain with specific equipment. Cases of the use of the architecture can be found from Table 11. The services can be used from higher to lower levels or vice versa. Certain sets or services can be restricted using authentication schema to cover only set users. An example of this would be weather forecasts and courses of actions (COA) in SA level 3 and Strategic. A weather forecast would be shared all the way to the tactical level but COAs would be strictly limited to high command use.

	Service SA level	MUSAS	SACIN
Strategic Joint services	3 Projection	- Weather forecast - COA	- Large-scale cascading dependencies - Preparation plans and simulations
	2 Comprehension	- Weather status - Operational status (mission, troops, status)	- Status of CI - Emergency supply status - Intelligence reports - Weather, politics, and media
	1 Perception	- Temperature, humidity, and wind at a given point - Locations of the troops	- Temperature, humidity, and wind at a given point
Operational Services	3 Projection	- Terrain analysis (mobility) - Enemy movement analysis - COA	- Local effects and predictions on cascading dependencies
	2 Comprehension	- Maps - Mission planning - Operational weather status	- Effects of current situation on other actors - Status of the critical source systems
	1 Perception	- Information feeds from tactical units (location, status)	- Combined tactical information
Tactical Services and networks	3 Projection	- Tactical-level COA - Estimations about the location and time of contact with the hostile forces	- Cascading dependencies in a specific case (source system, sector of CI)
	2 Comprehension	- Team location - Blueprints, maps - Mission/orders	- Linked knowledge on affecting source system in area - Knowledge of status in a single source system
	1 Perception	- BFT locations - Enemy locations	- Notable events in source system - Incidents and events

Table 11 - Examples of service-enabled SA in MUSAS and SACIN

The service structure enabling this is shown in Figure 30. In this construction, the JDL model is the architectural glue for the data fusion. The purpose of the JDL is to create a simple layout for the service structure, which is used to separate the services. As described earlier, Endsley's three-level model can be applied to the JDL model. In this architecture, the approach is technical and is not to be confused with the SA levels in the operator's mind. This approach is aimed at creating the baseline for software engineers to separate the services. When the services are implemented according to Endsley's levels, a set service layer is created. These layers can be used in different levels of the infrastructure (strategic, operational, and tactical) to support the service set. Services can be user interoperable to create new services as in SOA solutions. The core component in this structure is the goal-directed task analysis, which is the core tool in defining what the operator needs to accomplish. Based on this information, the user interface can be built to support the actual SA needs of the user. This is accomplished by the architecture, which by nature leverages the power of the SA levels, and service-oriented architecture and in addition, focuses on the user.

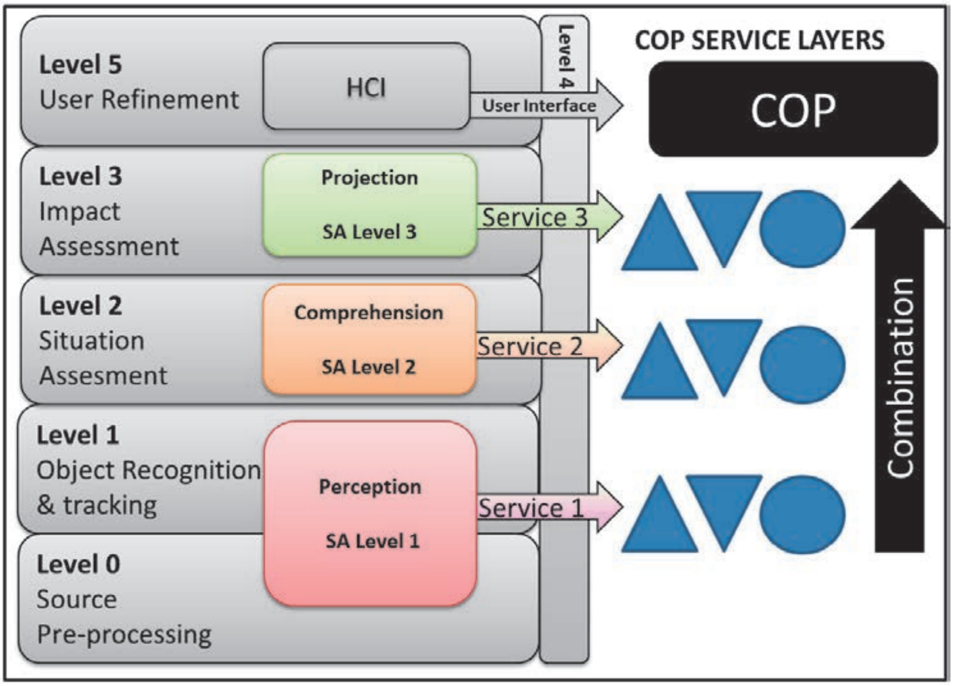

Figure 30 - Service layers

The GDTA's role in the design is to recognize the services vital to support the user's SA needs. Naturally, the process of recognition is unique for any operator and it enables fast deployment of a suitable role-based UI for the user. The framework is technically built so that the SA levels and operational service levels are taken into account at the time of service deployment. This approach makes sure that the user interface has the components ready for the SA-oriented design.

In the case of SACIN and MUSAS, the architecture has not been built with technology-enabled SA as the focus has been on the user interface and data fusion. This approach to SACIN and MUSAS is presented in P [VIII] and the implementation is still to be done. A point worth noting is that the MUSAS and SACIN actually present a great deal of features in terms of architecture and use, which support the transformation.

5

RESULTS AND CONCLUSIONS

In this chapter, the results of the papers corresponding to the research objectives are presented. This chapter also summarizes the contributions of the author to each publication and the main results in the presented material from each publication.

The main research question is:

Is it possible to support situation awareness with a common operating picture in two different environments with off-the-shelf technology?

The answer to this question is presented by using the three research objectives. In the following subchapters, the structure of the research problem will be examined and the results will be presented to answer the main research question, which is the composition of the research objectives.

5.1 Research objectives

The research objectives are presented in Table 12. From this table, the relation and sub-objectives can also be examined. As stated in the introduction, the research consists of the two main research topics, which are merged in research objective 3 to provide a common structure. The types of the publications represent the approach in the given research objective and are based on the author's opinion.

The types used in this thesis are:

- Conceptual
    - The paper contains a conceptual model or a concept of operations of the planned system.
- Architectural
    - The paper contains an architectural approach in order to separate logically the planned system into components that can be reasonably implemented.
- Empirical
    - The paper presents an implemented entity or a sub-entity, which is documented or reported in the publication.
- Experiment
    - The paper contains results from an end user testing session or questionnaire related to the developed system.

Publication	Objectives	Research Objective	Type
RO 1: Does multi-sensors-enabled data fusion provide value and support SA in dismounted operations in an urban area?			
I	Would a shared service structure provide advantages in the creation of a COP in shared C2 systems?	RO 1.1	Conceptual and empirical
II	Is it possible to improve tactical local area network (WLAN) with decentralization?	RO 1.2	Conceptual
III & IV	Does information integration and a shared sensor structure enable improved performance of dismounted troops with off-the-shelf technology?	RO 1.3	Conceptual, Empirical, Experiment, Architecture
RO 2: Is it possible to support SA in a situation room environment in terms of critical infrastructure?			
V & VIII	Is it possible to create and share the COP of critical infrastructure with off-the-shelf technology?	RO 2.1	Conceptual, Architectural, Experiment, Empirical
VI	What are the requirements for a critical infrastructure operator in terms of the COP?	RO 2.2	Conceptual
VII	Is it possible to visualize the COP of critical infrastructure so that it supports SA?	RO 2.3	Experiment, Empirical
RO 3: Is it possible to support situation awareness in different environments with a common service architecture?			
IX	Is it possible to support SA in different environments with a common service architecture?	RO 3	Architectural, Conceptual

Table 12 - Research objectives and types

5.2 Research objective 1

Research objective 1 focused on the creation and sharing of SA amongst troops operating in the field of urban area warfare. In paper [I], the foundations for troops operating with mobile networks and devices were presented. Moreover, the service-based approach was introduced. RO 1.1 is answered by the operational concept and implemented demonstrator. The result was that it is possible to improve the COP with the shared architecture enabling an improved SA. However, this study did not include a field test examination and was conducted in the laboratory environment. P [I]

In P [II], the technical storing of the COP was studied in terms of resilience and the constantly moving and evolving situation. In P [I] & [II], the approach is through the use of a pure MANET solution from the device level, complemented with base stations. In terms of RO 1.2, P [II] presented the logic and concept for distributing COP inside a MANET solution using COTS products. P [I] & [II] complement the approach by combining a service-based approach with a distributed COP and therefore RO 1.2 can be seen as having been fulfilled.

In [III] and [VI], a more polished system based on the earlier systems is presented. RO 1.3 addresses the issue of system-wide implementation and the solution is based on the created concept and proof-of-concept system MUSAS, which implements the main features. The concept and implementation enabled the users' test and evaluation events. The main problems to be solved are the information fusion and distribution in a complex environment in near-real time and as automated as possible. This was achieved in the final demonstration and users' tests utilizing all the components in the system. It was proven that complex systems could be implemented upon a COTS basis to support troops on the move. The field-test results and implementation make the case that RO 1.3 can be fulfilled. P [III] & P [IV]

Solutions for RO 1.1–1.3 have been given in the earlier chapter and the summarizing RO 1 (Does multi sensors-enabled data fusion provide value and support SA in dismounted operations in an urban area?) is being answered with P [I], [II], [III], and [IV]. As an entity, P [I] and [II] provide the base for the continuation of the work and the final environment is set up in P [III] and [IV]. The main results from the events are the implemented environment complemented by the field tests. The delivery of the COP enabled the troops to see two rooms further with the proposed technology and to synchronize their operations. By combining the RO 1.1–1.3, the RO 1 can be accepted as fulfilled.

5.3 Research objective 2

The second research objective focuses on the situation room environment where the operator plays a central role. In this RO, P [V] & [VII] are focused on the concept and architecture of building such a system. RO 2.1 examines the feasibility and technical as well as architectural means of implementing such a system. The business case is also taken into account; to whom and why the system is built is presented. The main challenges are the location of information, the amount of information, and the information-handling scheme in addition to the analysis of the gained information. Along with these publications, the actual proof-of-concept system was implemented and tested using limited use cases. This implementation was tested and developed to fulfill the needs of RO 2.1. As the implemented environment was able to achieve the user tests and scenarios, RO 2.1 is fulfilled.

The requirements for the operator are examined in RO 2.2. Clearly identifying the suitability of the COP is one of the main tasks for improving the usability and feasibility of the system. In P [VI], GDTA analysis is performed. In these tests, the main information needs for the operator in CI were discovered. P [VI] provides answers to RO 2.2 by explicitly defining the main information requirements for the operator.

RO 2.3. focuses on the visualization and the feasibility. The reason for a COP to exist is the users' improved SA. The results of the earlier implementations are placed into the user test in P [VII]. The main goal was to discover if the concept and implemented system actually contribute to the SA and the usability was evaluated. The SUS average score with standard deviation was 77.4 P [VIII], which is a good result as the global average score is 68 [139]. A SAGAT test was also performed, complemented with an eye tracking test. From P [VII], it can be seen that the usability and SA of the use case was formed. This confirms RO 2.3 as being successful.

The question asked by RO 2 (Is it possible to support SA in a situation room environment in terms of critical infrastructure?) is answered with RO 2.1–2.3 with P [V]–[VII]. As publications, P [V] and P [VII] put the focus on the system-level operation, while P [VI] and P [VII] focus on the end user and building SA. First, P [VI] examines the requirements for the created system and P [VII] will conduct user tests and measure the actual levels of SA in the test scenario with the implemented system during P [V] and P [VII]. First, it is proven that the creation of such a system is possible (RO 2.1), and later the requirements for the COP (RO 2.2) are defined and, finally, with the creation of SA with the system having been proved (RO 2.3), the RO 2 can be stated as having been fulfilled.

5.4 Research objective 3

Research objective 3 (Is it possible to support SA in different environments with a common service architecture?) aims to combine the conceptual and architectural solutions derived from RO 1 and RO 2 into a re-usable and scalable solution for the means of SA at the technical level. In [XI], the created service structure is presented and it is discussed in subsection 4.4 of this dissertation. The created approach can be considered as one of the main contributions of the dissertation. In this approach, the user's SA is not the only entity in the system containing SA elements. The entire service-based structure is being built to support the creation, sharing, and usability of SA, starting from the technical perspective. This structure is still in its conceptual phase and has not yet been validated with implementation or field testing. Based on P [IX], it is feasible to research the topic further on by combining the SA analysis with a technical framework. Based on P [IX], RO 3 can be stated as partially fulfilled but the need for implementation and further testing exists.

5.5 The main research question

The main research question was formed to study the overarching goal of supporting SA in multiple environments using COTS products. (Is it possible to support situation awareness with a COP in two different environments with off-the-shelf technology?) The previous chapter defined the results for the research objectives, which form the basis for the answer to the main research question. RO 1 and 2 provided the fact that it is possible to support the SA with a digital COP specified for the task. Furthermore, the role of COTS was used in MUSAS P [III] and [IV] and SACIN P [V] and [VII] projects. The use case and improvements were found for both projects. Along with the RO 1 and 2, the main research question is answered with the implemented environments complemented with the field tests and SA tests (SACIN). As for the possibility of combining the service structure in multiple environments, RO 3 is partially fulfilled and the need for further examination exists. The main contributions of each publication to the main research question and research objectives are summarized in Table 13.

Research Objective	Publication	Type	Contributions of the publications to the research objects
1.1	I	Conceptual and empirical	• A concept for PDA devices in dismounted forces, including system architecture based on services • Component structure and model for the architecture • Implementation and limited tests of the design • Automatic role-based view in each device
1.2	II	Conceptual	• Decentralized model of COP in the tactical network
1.3	III	Conceptual, Empirical, Experimental, Architectural	• Information integration framework • Proof-of-concept system implementation (MUSAS) • Information fusion architecture • User interface • Field test
1.3	IV	Conceptual, Empirical, Experimental, Architectural	• High-level concept and full architecture • Integration in a larger scale • All the subsystems presented • Field test documentation
2.1	V	Conceptual, Architectural, Experimental, Empirical	• A concept for gathering and spreading information in CI • Presentation of implementation • Architecture
2.1	VIII	Conceptual, Architectural, Experimental, Empirical	• Presentation of the entire scope and alignment of the concept • Component structure and purpose • User test and results
2.2	VI	Conceptual	• Requirements for CI operators' SA and communication needs • GDTA analysis • Environmental observations
2.3	VII	Experimental, Empirical	• Comprehensive presentation on visualization and SA test results • HCI development steps
3	IX	Architectural, Conceptual	• Overarching model for SA framework supporting technical and mental creation of SA

Table 13 - Contributions

5.6 Contributions of the author to the publications

The author of this thesis is the sole author of the papers [II] and [IX]. In [III], Professor Jouko Vankka provided invaluable insights and opinions to support the paper, but the paper was written by the author of the dissertation.

In [I], the author was responsible for building the software and also contributed to the concept including the presented components in the battlefield architecture.

In [V], the author is the main contributor and was responsible for the general concept and the structure. The technical architecture was planned in cooperation with the project group.

In [IV], the author contributed by presenting the entire information fusion model and user interface implementation and participated in forming the overall concept.

In [VI], the author contributed to the binding of goals to the concept and provided insights and comments.

In [VII], the author contributed to the concept presented in the publication and provided comments to the paper.

In [VII], the author contributed to the concept of the system and by providing comments and feedback to the overall publication.

6

DISCUSSION

This research presents architectures and concepts, which are built for the end user's needs. The combination of architectures takes into account the role of situation awareness (SA), not only at the user interface level, but also throughout the entire system, starting from the technical approach.

In chapter 0 the research gaps were identified and examined. The information systems framework for this thesis is presented in Figure 2, where the link between environment, IS research and additions to knowledge base was realized (see Figure 2). In chapter 5 the actual additions to knowledge base are examined by individually explaining the results in terms of the research objectives (Table 3 & Table 13) and publications.

The literature review is presented in chapter 1.3 where the feature sets for dismounted forces (see Table 1) and monitor room environment (see Table 2) are realized. The research gap was identified in chapter 1.4 and the main gap areas are the following:

- Application of data fusion to service-based solutions for the creation of the common operating picture (COP)
- Integration of the SA technical framework
- Combination of indoor location techniques with the COP system in urban area warfare
- Combination of the architectures for heterogeneous environments

These findings were explored in the form of research objectives and answered in the publications. The types of the research questions are *method or means of development* and *feasibility* and the thesis aims to discover how the present situation can be improved and what the effective ways of achieving the desired result are. This approach can be realized from the results, which focus near the field of engineering research. The technical approach required a great deal of computer programming and empirical testing in different areas (technical and SA). As for the research contributions, this research improves the understanding of how people use software, identifies new problems, and characterizes new tools. Evidence that one approach is preferred over another is also gained in many areas, such as architectural design and UI design.

6.1 Contributions of the dissertation

The dissertation provides novel approaches to SA design in two different use cases. The research contains two proof-of-concept systems for actual evaluation and testing of the system.

Therefore, the main contributions of this dissertation are as follows:

- The created concept, architecture, and implementation for urban area warfare SA support
- The created concept, architecture, and implementation for the situation room environment for supporting the SA of the operator
- The model that combines the two environments, presenting a common service structure for the creation, and sharing COP

The research combines the approaches of commercial industry to the academic research by a combination of COP creation to the sensor-based detection systems. The dissertation presents an approach where multiple scientific projects in the field are combined into a usable platform offering COP to the selected use cases. Moreover, the solution is able to integrate other products with the created platform. Furthermore, the role of SA is being taken into account not only on the user side but also on the architectural level. The novel feature combinations of the solutions presented by this dissertation can be realized from Table 14, which is based on Table 1 and 2. Moreover, the research also combines the two environments with a common service structure (presented in column "Service Structure").

MUSAS	**SACIN**	**Service Structure**
• OTS technology • BFT • SLAM • Sensor Fusion • Isolated use enabled • MANET • Wearable user interfaces • Location indoors	• OTS technology • Agent-based solution • Brokered architecture • Distributed use • JDL model • Monitoring room environment • Cascading dependencies • SA-oriented user interface	• OTS technology • SA-enabled architecture • Role and task-based user interfaces • Independent operation on different layers • Rapid user interface creation

Table 14 - Features

Numerous different approaches the modelling of CI exists in contemporary literature but in many cases SA are not being addressed and the focus is in specific system. The proposed model attempts to fill this gap by considering the requirement to model a large number of systems and real-time aspects and take SA into consideration. Moreover, the SA is being taken into the fundamentals of the concept so that it is built in the technical framework.

An important contribution of the MUSAS is providing a solution for localization based situation awareness using multiple different localizations and mapping methods. If compared to other systems of similar type, MUSAS does not rely on pre-existing infrastructure. The networks are autonomously built using Wireless Sensor Networks (WSN) and Wireless Local Area (WLAN) technologies. The system is able to map the unknown areas and combine it with the existing in formation. Moreover, the system is able to share the information real time as well as operate both outdoors and indoors and has through wall observation capabilities.

In many cases, the concept itself is considered as a main result of a research. In the dissertation, it is worth highlighting that, on top of the concepts, an architectural solution is also built and implemented. This has created a situation where the feasibility of the concepts has been able to be tested with the actual users, and not only in theory but in actual use cases created for the systems. For the same reason, a large part of the work done in order to make this dissertation is hidden; thousands of lines of code have been produced during the projects by the project group and by the author.

In terms of definitions, the approach of the DOD to the COP [6] is too limiting in the modern systems. By binding COP to only the display level would limit the usability of the term in a dramatic way. One option for addressing the issue would be to use a service-based approach where the user interface is not in the key role. In this dissertation, the COP is seen as a service structure containing the current situation in a shareable and extendable set. This can be seen as a definition-level contribution.

The conclusions and concepts of the systems have been presented in many conferences and inside the Finnish Defence Forces in several cases in the aid of similar projects. This can be seen as a concrete result of academic research contributing to an actual system development. As stated concerning the limitations of this research, no real operational implementation is being targeted. Still, the most important goal is to estimate the future of such systems and the actual contribution to system development would be the highest goal, which is not easy to achieve.

The technical development will most likely maintain the technical nature, as it is technical work; the architecture highlights the role of the user in the technical process. In addition, the concept focuses on the reasons for the systems to exist. Both use cases have been verified to be important by interviews and testing sessions. This approach has led the research to specific problems, which are addressed by technical means using an SA-oriented approach.

6.2 Assessment of the dissertation and critique

The contributions to science, or additions to knowledge base from this thesis are formed by first realizing the research gap and by building the research objectives and research questions in relation to the gap. The process and relation to the design science paradigm is presented in Figure 2. The addition to knowledge base is described in chapter 5 in detail, but the high-level additions are as followed:

- Novel concepts, architectures and implementations
- Novel feature combinations (see Table 14)
- The service structure concept including built-in SA
- The experiences and results of the tests of the systems (guidelines for other researchers)

In Table 15 the presented gap areas are described in relation to the main contributions. The main gap areas have been addressed with a main concepts leading to the end user tests. The novel feature sets compared to other systems by MUSAS and SACIN are shown in tables 1 & 2.

<table>
<tr><th>Gap areas
(Ch. 1.4)</th><th>Contributions
(Ch. 5& 6.1)</th><th>Evaluation</th></tr>
<tr><td>Integration of the SA technical framework</td><td>The created concept, architecture, and implementation for the situation room environment for supporting the SA of the operator</td><td>Concept includes SA as a fundamental building block. The implementation and tests with SA enabled common service structure are in future work.</td></tr>
<tr><td>Application of data fusion to service-based solutions for the creation of the common operating picture (COP)</td><td rowspan="2">The model that combines the two environments, presenting a common service structure for the creation, and sharing COP</td><td rowspan="2">Both environments have concept and implementations as well as end user tests.

The concept for common service structure has been presented</td></tr>
<tr><td>Combination of the architectures for heterogeneous environments</td></tr>
<tr><td>Combination of indoor location techniques with the COP system in urban area warfare</td><td>The created concept, architecture, and implementation for urban area warfare SA support</td><td>Multiple indoor location techniques as well as interfaces for applying new sensor systems are implemented</td></tr>
</table>

Table 15 - Gap and contributions

The concepts and architecture form a good baseline for other researchers to start their work and build new solutions with increased capabilities. As educational and instructive the implementation and testing for the research group are, the implemented system is always only one instance of the concept. This means with different implementation of the same concept it is possible to get different results. In terms of logic, this affects on performance and in terms of visualization, the effect is in usability.

Even though the dissertation contains a large amount of implemented and tested solutions, not all the features were implemented. It would not have been possible or reasonable to implement all the features discussed in the concept level. As a result, the test sessions have been selected and built to support the implemented functionality.

In general, it can be stated that the use cases and system-wide approach used in this dissertation may be too large. All the presented systems contain vast amounts of subsystems, which itself might be worth a dissertation. This approach was, however, taken as the role in the research project, plus the desired publications were aimed at the system level. In the case of MUSAS and SACIN, the implementation was made to evaluate the feasibility. The proof-of-concept level enables user tests to be performed and feedback to be generated from the system. In the case of the combined service structure, it was not possible to implement the architecture due to time constraints.

As for the testing, the MUSAS system did not experience the same type of user tests as in SACIN. During the MUSAS project on the role of SA, testing was in a different form and the main results were gathered at the field test session. In SACIN, the approach contained quantitative methods to measure the level of SA in certain use cases and provided invaluable insight on how the operator experiences the situation.

Naturally, in both projects some shortcuts were taken if compared to real-world scenarios. An example of this would be power consumption and information security. These aspects were recognized as research worthy but were not included in the concept or implementation.

6.3 Validity and reliability

With the SA measurement techniques, it is important to address the reliability and validity to make sure that the methods really work [164]. In the field of SA measurement, some research has been conducted, which has not been able to validate clearly all the methods [165, 166]. As validity focuses on measuring if an instrument measures what it is supposed to, the validity in this research can be examined using the SA test methods for end users [167]. For the possibility of validating whether the created concept, architecture, and implementation are valid, end user tests are needed. These tests are the only source for understanding if the system is focusing on the right issues. The tests conducted in the field for SA offer the most objective approach to the actual improvements and results from the end users' perspective.

To illustrate the difference of reliability and validity, Salmon proposed a rifle sharpshooter comparison; the reliability of shooting refers to the grouping, whereas the validity measures the distance from the goal to the individual hit [94]. In order for a test to be successful, the hits need to be in a tight grouping and the focal point of all hits needs to be close to the target.

Reliability focuses on measuring the performance of empirical methods [168]. In the case of this study, the repeatability is at a high level as the core contribution is a software tool. The scenarios can be retested with different user groups or settings as the UI and functionality will not change (unless otherwise desired). Naturally, the reliability of the test methods themselves would need to be validated, but that is out of the scope of this dissertation.

As the core contributions are in concepts, architectures, and implementations, the possibility of fragmenting the specific components in both the selected systems exists for later examination. Moreover, the measurements of SA in SACIN can be seen as a quantitative approach. In addition, performance measures such as response time, logic stress tests, and connection tests are applicable. In the case of the study, the approach is system wide and the component level testing is not in scope.

With the combination of reliability and validity, the main entities providing enforcement are discussed in Table 16.

Validity	**Situation Awareness** - End user measurements (Are we building the right product for the right issue?) - Validity in the SA test methods (Are we measuring the right thing with the right methods?)	SART, SAGAT, and performance measures
	Implementation - Operational tests (Will our architecture work?)	Test sessions, end user queries
Reliability	**Situation Awareness** - Reproducibility (Are we able to validly reproduce the test situations and gain consistent results?) - Triangulation methods [169] (Can we confirm the result with different methods?)	Several SART, SAGAT, and performance measures
	Implementation - Functionality (Does our solution work reliably and consistently?)	Test sessions, end user queries

Table 16 - Reliability and validity

In the context of this research, the main researcher in the area human factors is Lauri Rummukainen who has conducted the actual tests and therefore has been the main evaluator of validity and reliability in SA tests. It is worth noting that SUS queries have been performed three times (77.5, 71.25, and 77.4). [P VII & VIII]

6.4 Future research

The future research contains the implementation of service-based architecture supporting SA and testing sessions aimed for feasibility, performance, and creation of new user interfaces. If the architecture is successful, the implementation of a new user interface for a specific mission or task would be straightforward and efficient.

The most important target for current research in SACIN is the analysis of a cascading event in CI. The component and interfaces are ready but the logic still needs further development. The component is placed on the JDL level 3 (see Figure 30).

In the case of MUSAS, the 3D imaging of the blueprint complemented with 3D guidance is required for successful operations in the constructed area. The components were studied at the concept level, but 3D solutions have been implemented. In MUSAS, the integration of drones to the system was also under active planning. This would provide improved detection of hostile forces and could be used to update the digital maps.

In the current systems, the enabling of full connectivity toward the other systems would present an interesting use case where the system could be placed in an operative situation and the functionality could be estimated. At the same time, this would take the scope out from the academic level toward productization and operational use.

REFERENCES

[1] Merriam-Webster Dictionary, "Ad Hoc," in *Merriam-Webster Online*, 2016.

[2] Merriam-Webster Dictionary, "Architecture," in *Merriam-Webster Online*, 2015.

[3] United States Department of Defense, "C2," in *DOD Dictionary of Military and Associated Terms*, 2015.

[4] M. Rouse and C. Callender. (2015, 24.2.). *COTS, MOTS, GOTS, and NOTS* [Online]. Available: http://searchenterpriselinux.techtarget.com/definition/COTS-MOTS-GOTS-and-NOTS

[5] Microsoft. (2015, 24.2.). *Commercial Off-The-Shelf (COTS)* [Online]. Available: https://www.techopedia.com/definition/1444/commercial-off-the-shelf-cots

[6] United States Department of Defense, "Common Operational Picture," in *DOD Dictionary of Military and Associated Terms*, 2012.

[7] United States Department of Defense, "Concept," in *DOD Dictionary of Military and Associated Terms*, 2015.

[8] Merriam-Webster Dictionary, "Cloud Computing," in *Merriam-Webster Online*, 2015.

[9] European Parliament and Council of the European Union, "COUNCIL DIRECTIVE 2008/114/EC of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection," in *Official Journal of the European Communities*. Brussels, 2008.

[10] Merriam-Webster Dictionary, "Cyber," in *Merriam-Webster Online*, 2015.

[11] C. Greer and D. Wollman. (2015, 4.4.). *Cyber-Physical Systems* [Online]. Available: http://www.nist.gov/cps/

[12] F. Castanedo, "A Review of Data Fusion Techniques," *The Scientific World Journal*, vol. 2013, p. 19, 2013.

[13] A. Chapanis, "To Communicate the Human Factors Message, You Have to Know What the Message Is and How to Communicate It," in *Human Factors Society Bulletin*, 2009, pp. 1-4.

[14] Merriam-Webster Dictionary, "Off-the-shelf," in *Merriam-Webster Online*, 2015.

[15] WebFinance Inc. (2015, 19.5.). *proof-of-concept* [Online]. Available: http://www.investorwords.com/3899/proof_of_concept.html

[16] Merriam-Webster Dictionary, "Schema," in *Merriam-Webster Online*, 2015.

[17] Microsoft. (2015, 24.2.). *Service-Oriented Architecture (SOA)* [Online]. Available: https://msdn.microsoft.com/en-us/library/bb977471.aspx

[18] M. R. Endsley, "Design and evaluation for situation awareness enhancement," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 1988, pp. 97-101.

[19] National Telecommunications & Information Administration (NTIA) U.S. Department of Commerce, "systems design," in *Federal Standard 1037C*, 1996.
[20] M. R. Endsley, *Designing for Situation Awareness: An Approach to User-centered Design*, Second ed. USA: CRC Press, 2011.
[21] M. R. Endsley and S. S. Connors, "Situation awareness: State of the art," in *Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE*, 2008, pp. 1-4.
[22] K. Jordan, "Military Science," in *Encyclopedia of Military Science*, 2013.
[23] University of Turku. (2015, 15.11.). *Tietotekniikan, elektroniikan ja tietoliikennetekniikan koulutusohjelma 2013-2013* [Online]. Available: https://nettiopsu.utu.fi/opas/koulutusohjelma.htm?opsId=159&uiLang=fi &lang=fi&lvv=2012&koulohj=DITY2
[24] T. Mai. (2015, 10.12.). *Technology Readiness Level* [Online]. Available: https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html
[25] C. Onwubiko and T. Owens, Eds., *Cyber Command and Control: A Military Doctrinal Perspective on Collaborative Situation Awareness for Decision Making* (Situational Awareness in Computer Network Defense: Principles, Methods and Applications. Hershey, PA, USA: IGI Global, 2012, p.29-47.
[26] M. D. McNeese, M. S. Pfaff, E. S. Connors, J. F. Obieta, I. S. Terrell, and M. A. Friedenberg, "Multiple vantage points of the Common Operational Picture: supporting international teamwork," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 2006, pp. 467-471.
[27] G. Conti, J. Nelson, and D. Raymond, "Towards a cyber common operating picture," in *5th International Conference on Cyber Conflict (CyCon)*, 2013, pp. 1-17.
[28] J. Loomis, R. Porter, A. Hittle, C. Desai, and R. White, "Net-centric collaboration and situational awareness with an advanced User-Defined Operational Picture (UDOP)," in *International Symposium on Collaborative Technologies and Systems (CTS)*, 2008, pp. 275-284.
[29] S. Butler, D. Diskin, N. Howes, and K. Jordan, "Architectural design of a common operating environment," *IEEE Software*, vol. 13, pp. 57-65, 1996.
[30] R. Butler, D. Deckro, and J. Weir, "Using Decision Analysis to Increase Commanders' Confidence for Employment of Computer Network Operations," *IO Sphere*, 2005.
[31] R. E. Balfour, "An Emergency Information Sharing (EIS) framework for effective Shared Situational Awareness (SSA)," in *Systems, Applications and Technology Conference (LISAT), 2014 IEEE Long Island*, 2014, pp. 1-6.
[32] R. E. Balfour, "Next generation emergency management common operating picture software/systems (COPSS)," in *Systems, Applications and Technology Conference (LISAT)*, Long Island, 2012, pp. 1-6.

[33] O. Balet, J. Duysens, J. Compdaer, E. Gobbetti, and R. Scopigno, "The Crimson Project. Simulating populations in massive urban environments.," in *World Congress on Computational Mechanics (WCCM8)*, 2008.

[34] A. Ahmad, O. Balet, J. Himmelstein, A. Boin, M. Schaap, P. Brivio*, et al.*, "Interactive simulation technology for crisis management and training: The INDIGO Project," in *Proceedings of the 9th International ISCRAM Conference*, 2012.

[35] A. Boin, F. Bynander, G. Pintore, F. Ganovelli, G. Leventakis, A. Ahmad*, et al.*, "Building an IT platform for strategic crisis management preparation," in *10th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, 2014, pp. 20-27.

[36] J. Himmelstein, O. Balet, F. Ganovelli, E. Gobbetti, M. Specht, P. Mueller*, et al.*, "The v-city project," in *VAST: International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage-Short and Project Papers*, 2011, pp. 57-60.

[37] M. Pollefeys, D. Nistér, J.-M. Frahm, A. Akbarzadeh, P. Mordohai, B. Clipp*, et al.*, "Detailed real-time urban 3d reconstruction from video," *International Journal of Computer Vision,* vol. 78, pp. 143-167, 2008.

[38] N. Cornelis, B. Leibe, K. Cornelis, and L. Van Gool, "3d urban scene modeling integrating recognition and reconstruction," *International Journal of Computer Vision,* vol. 78, pp. 121-141, 2008.

[39] L. Zebedin, J. Bauer, K. Karner, and H. Bischof, "Fusion of feature-and area-based information for urban buildings modeling from aerial imagery," in *Computer Vision–ECCV*, ed: Springer, 2008, pp. 873-886.

[40] Google Inc. (2014, 11.4.). *Google Project Tango* [Online]. Available: http://www.google.com/atap/projecttango/

[41] T. Erl, *Service-Oriented Architecture (SOA) Concepts, Technology and Design*, 2005.

[42] S. S. Yau, D. Huang, H. Gong, and H. Davulcu, "Situation-awareness for adaptive coordination in service-based systems," in *29th Annual International Computer Software and Applications Conference*, 2005, pp. 107-112.

[43] S. S. Yau and L. Junwei, "Incorporating situation awareness in service specifications," in *Ninth IEEE International Symposium on Object and Component-Oriented Real-Time Distributed Computing*, 2006, p. 8.

[44] C. J. Matheus, M. M. Kokar, and K. Baclawski, "A core ontology for situation awareness," in *Proceedings of the Sixth International Conference on Information Fusion*, 2003, pp. 545-552.

[45] M. Durresi, A. Durresi, and L. Barolli, "Hierarchical Communications for Battlefields," in *21st International Conference on Advanced Information Networking and Applications Workshops (AINAW '07)*, 2007, pp. 690-695.

[46] T. Saarelainen, "White Force Tracking (WFT)," in *ECIW2009-8th European Conference on Information Warfare and Security: ECIW 2009*, 2012, p. 216.

[47] United States Department of Defense, *Joint Vision 2020*: Washington DC: Government Printing Office, 2001.

[48] SoldierMod.com. (2012, 20.12.). *Programmes at a Glance: December 2012, report* [Online]. Available: http://www.soldiermod.com/volume-10/pdfs/articles/programmes-overview-may-2013.pdf
[49] R. Dietterle, "The future combat systems (FCS) overview," in *Military Communications Conference*, 2005, pp. 3269-3273 Vol. 5.
[50] A. Taylor, "Report : Future soldier 2030 Initiative," 2009.
[51] L. J. Williams, "Small unit operations situation awareness system (SUO SAS): an overview," in *Military Communications Conference*, 2003, pp. 174-178.
[52] V. Kaul, C. Makaya, S. Das, D. Shur, and S. Samtani, "On the adaptation of commercial smartphones to tactical environments," in *Military communications conference*, 2011, pp. 2205-2210.
[53] Y. Kalley, "Improved decision support system (IDSS) transforming the smart network-edge," in *International Symposium on Collaborative Technologies and Systems*, 2009, pp. 76-84.
[54] S. M. Diamond and M. G. Ceruti, "Application of Wireless Sensor Network to Military Information Integration," in *5th IEEE International Conference on Industrial Informatics*, 2007, pp. 317-322.
[55] G. Boggia, P. Camarda, L. Grieco, and G. Zacheo, "Toward wireless networked control systems: an experimental study on real-time communications in 802.11 WLANs," in *IEEE International Workshop on Factory Communication Systems* 2008, pp. 149-155.
[56] T. Saarelainen and J. Jormakka, "Computer-aided warriors for future battlefields," in *Proceedings of the 9th European Conference on Information Warfare and Security (ECIW'09), Lisbon, Portugal*, 2009, pp. 224-233.
[57] T. Saarelainen and J. Jormakka, "Collaboration and Command Tools for Crises Management," in *Global Security, Safety, and Sustainability*, ed: Springer, 2010, pp. 28-38.
[58] L. Briesemeister, "Sensor data dissemination through ad hoc battlefield communications," in *Communication Networks and Distributed Systems Modeling and Simulation Conference (CNDS)*, 2003.
[59] T. Bokareva, W. Hu, S. Kanhere, B. Ristic, N. Gordon, T. Bessell, *et al.*, "Wireless sensor networks for battlefield surveillance," in *Proceedings of the Land Warfare Conference*, 2006, pp. 1-8.
[60] M. Kulich, J. Kout, L. Preucil, R. Mazl, J. Chudoba, J. Saarinen, *et al.*, "PeLoTe - a heterogeneous telematic system for cooperative search and rescue missions," *in conjunction with Urban Search and Rescue: from Robocup to Real World Applications*, 2004.
[61] J. Allen, Q. Duong, and C. Thompson, "Natural Language Service for Controlling Robots and Other Agents," *IEEE Integration of Knowledge Intensive Multi-Agent Systems (KIMAS-05)*, pp. 18-21, 2005.
[62] S. Ahlberg, P. Hörling, K. Johansson, K. Jöred, H. Kjellström, C. Mårtenson, *et al.*, "An information fusion demonstrator for tactical intelligence processing in network-based defense," *Information Fusion*, vol. 8, pp. 84-107, 2007.

[63] J. L. Paul, "Smart Sensor Web: Tactical battlefield visualization using sensor fusion," *Aerospace and Electronic Systems Magazine, IEEE,* vol. 21, pp. 13-20, 2006.
[64] S. K. Das, K. Kant, and N. Zhang, *Handbook on Securing Cyber-physical Critical Infrastructure*: Elsevier, 2012.
[65] Office of electricity delivery & energy reliability. (2015, 12.4.). *What is SmartGrid?* [Online]. Available: https://www.smartgrid.gov/the_smart_grid/
[66] W. J. Clinton, "Executive Order 13010 - Critical Infrastructure Protection," *Federal Register*, vol. 61, 1996.
[67] P. Pederson, D. Dudenhoeffer, S. Hartley, and M. Permann, "Critical Infrastructure Interdependency Modeling: a Survey of U.S. and International Research," *Idaho National Laboratory*, pp. 1-20, 2006.
[68] C. Alcaraz and J. Lopez, "Wide-Area Situational Awareness for Critical Infrastructure Protection," *Computer,* vol. 46, pp. 30-37, 2013.
[69] E. Casalicchio, E. Galli, and S. Tucci, "Federated Agent-based Modeling and Simulation Approach to Study Interdependencies in IT Critical Infrastructures," in *11th IEEE International Symposium of Distributed Simulation and Real-Time Applications*, 2007, pp. 182-189.
[70] S. M. Rinaldi, J. P. Peerenboom, and T. K. Kelly, "Identifying, understanding, and analyzing critical infrastructure interdependencies," *Control Systems, IEEE,* vol. 21, pp. 11-25, 2001.
[71] A. Attwood, M. Merabti, P. Fergus, and O. Abuelmaatti, "SCCIR: Smart Cities Critical Infrastructure Response Framework," in *Developments in E-systems Engineering (DeSE),* 2011, pp. 460-464.
[72] W. Tolone, D. Wilson, A. Raja, W.-n. Xiang, H. Hao, S. Phelps, *et al., Critical Infrastructure Integration Modeling and Simulation* vol. 3073: Springer Berlin Heidelberg, 2004.
[73] Z.-y. Liu and B. Xi, "COPULA model design and analysis on critical infrastructure interdependency," in *International Conference on Management Science and Engineering (ICMSE)*, 2012, pp. 1890-1898.
[74] C. Wang, L. Fang, and Y. Dai, "National Critical Infrastructure Modeling and Analysis Based on Complex System Theory," in *First International Conference on Instrumentation, Measurement, Computer, Communication and Control*, 2011, pp. 832-836.
[75] R. Zimmerman, "Decision-making and the vulnerability of interdependent critical infrastructure," in *IEEE International Conference on Systems, Man and Cybernetics*, 2004.
[76] R. Zimmerman and C. E. Restrepo, "Analyzing cascading effects within infrastructure sectors for consequence reduction," in *IEEE Conference on Technologies for Homeland Security*, 2009, pp. 165-170.
[77] J. Kopylec, A. D'Amico, and J. Goodall, "Visualizing cascading failures in critical cyber infrastructures," in *Critical Infrastructure Protection*, ed: Springer, 2007, pp. 351-364.
[78] The White House, "Executive Order -- Improving Critical Infrastructure Cybersecurity," Washington DC,2013.

[79] A. Koskinen-Kannisto, "Situational awareness concept in a multinational collaboration environment: challenges in the information sharing framework," Ph.D. dissertation, Series 1, n: o 31, The Finnish National Defence University, 2013.
[80] R. H. Von Alan, S. T. March, J. Park, and S. Ram, "Design science in information systems research," *MIS quarterly*, vol. 28, pp. 75-105, 2004.
[81] A. R. Hevner, "A three cycle view of design science research," *Scandinavian journal of information systems*, vol. 19, p. 4, 2007.
[82] University of Jyväskylä. (2015, 11.12.). *Mapping Research Methods* [Online]. Available: https://koppa.jyu.fi/avoimet/hum/menetelmapolkuja/en/methodmap/philosophy-of-science
[83] M. Shaw, "What makes good research in software engineering?," *International Journal on Software Tools for Technology Transfer*, vol. 4, pp. 1-7, 2002.
[84] V. R. Basili, "The experimental paradigm in software engineering," in *Experimental Software Engineering Issues: Critical Assessment and Future Directions*, ed: Springer, 1993, pp. 1-12.
[85] S. Easterbrook. (2014, 25.2.). *Basics of Empirical Research* [Online]. Available: http://www.cs.toronto.edu/~sme/CSC2130/03-basics.pdf
[86] M. R. Endsley, "Toward a Theory of Situation Awareness in Dynamic Systems," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 37, pp. 32-64, 1995.
[87] B. Brehmer, "Command and control as design," in *15th International Command and Control Research and Technology Symposium (ICCRTS)*, Santa Monica, USA, 2010.
[88] J. Robertson, "Integrity of a common operating picture in military situational awareness," in *Information Security for South Africa (ISSA)*, 2014, pp. 1-7.
[89] R. D. Gilson, "Special issue preface," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 37, pp. 3-4, 1995.
[90] D. B. Beringer and P. A. Hancock, "Exploring situational awareness: A review and the effects of stress on rectilinear normalisation," in *Fifth International Symposium on Aviation Psychology*, Columbus, Ohio, 1989, pp. 646-651.
[91] N. A. Stanton, P. Chambers, and J. Piggott, "Situational awareness and safety," *Safety Science*, vol. 39, pp. 189-204, 2001.
[92] G. Bedny and D. Meister, "Theory of activity and situation awareness," *International Journal of Cognitive Ergonomics*, vol. 3, pp. 63-72, 1999.
[93] K. Smith and P. Hancock, "Situation awareness is adaptive, externally directed consciousness," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 37, pp. 137-148, 1995.
[94] P. M. Salmon, "Distributed situation awareness: Advances in theory, measurement and application to team work," Ph.D. dissertation, Brunel University School of Engineering 2008.
[95] G. A. Klein, *A Recognition-Primed Decision (RPD) Model of Rapid Decision Making*: Ablex Publishing Corporation, 1993.

[96] U. Neisser, *Cognition and Reality: Principles and Implications of Cognitive Psychology*: WH Freeman/Times Books/Henry Holt & Co, 1976.
[97] M. R. Endsley, "Measurement of situation awareness in dynamic systems," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 37, pp. 65-84, 1995.
[98] M. R. Endsley, "A survey of situation awareness requirements in air-to-air combat fighters," *The International Journal of Aviation Psychology*, vol. 3, pp. 157-168, 1993.
[99] J. R. Boyd, "Organic Design for Command and Control," *A Discourse on Winning and Losing*, 1987.
[100] G. P. Tadda and J. S. Salerno, "Overview of cyber situation awareness," in *Cyber Situational Awareness*, ed: Springer, 2010, pp. 15-35.
[101] B. McGuiness and L. Foy, "A subjective measure of SA: The crew awareness rating scale (cars)," in *Poceedings of the First Human Performance, Situation Awareness, and Automation Conference*, 2000.
[102] M. R. Endsley, "Situation awareness global assessment technique (SAGAT)," in *Proceedings of the IEEE 1988 National Aerospace and Electronics Conference (NAECON)*, 1988, pp. 789-795.
[103] D. G. Jones and M. R. Endsley, "Sources of situation awareness errors in aviation," *Aviation, Space, and Environmental Medicine*, 1996.
[104] L. J. Sorensen, N. A. Stanton, and A. P. Banks, "Back to SA school: contrasting three approaches to situation awareness in the cockpit," *Theoretical Issues in Ergonomics Science*, vol. 12, pp. 451-471, 2011.
[105] S. Dekker and M. Lützhöft, "Correspondence, cognition and sensemaking: a radical empiricist approach to situation awareness," in *A Cognitive Approach to Situation Awareness: Theory, Measurement and Application.*, S. B. S. Tremblay, Ed., ed Aldershot, UK: Ashgate Publishing, 2004, pp. 22-41.
[106] M. R. Endsley, "Situation Awareness Misconceptions and Misunderstandings," *Journal of Cognitive Engineering and Decision Making*, vol. 9, pp. 4-32, 2015.
[107] P. M. Salmon, N. A. Stanton, G. H. Walker, C. Baber, D. P. Jenkins, R. McMaster, *et al.*, "What really is going on? Review of situation awareness models for individuals and teams," *Theoretical Issues in Ergonomics Science*, vol. 9, pp. 297-323, 2008.
[108] G. Klein, J. K. Phillips, E. L. Rall, and D. A. Peluso, "A data-frame theory of sensemaking," in *Expertise Out of Context: Proceedings of the Sixth International Conference on Naturalistic Decision Making*, 2007, pp. 113-155.
[109] U. Neisser, "Perceiving, anticipating and imagining," *Minnesota Studies in the Philosophy of Science*, vol. 9, pp. 89-106, 1978.
[110] L. A. Klein, *Sensor and Data Fusion: a Tool for Information Assessment and Decision Making* vol. 324: Spie Press Bellingham, 2004.
[111] F. E. White, "Data fusion lexicon," DTIC Document, 1991.
[112] A. N. Steinberg, C. L. Bowman, and F. E. White, "Revisions to the JDL data fusion model," *Proc. SPIE 3719, Sensor Fusion: Architectures, Algorithms, and Applications III*, vol. 3719, pp. 430-441, March 12, 1999.

[113] L. Perrochon, J. Eunhei, S. Kasriel, and D. C. Luckham, "Enlisting event patterns for cyber battlefield awareness," in *Proceedings of DARPA Information Survivability Conference and Exposition (DISCEX)*, 2000, pp. 411-422.

[114] N. A. Giacobe, "Application of the JDL data fusion process model for cyber security," in *Proc. SPIE*, 2010, p. 77100R.

[115] W. Elmenreich, "A review on system architectures for sensor fusion applications," in *Software Technologies for Embedded and Ubiquitous Systems*, ed: Springer, 2007, pp. 547-559.

[116] J. Llinas and D. L. Hall, "An introduction to multi-sensor data fusion," in *Proceedings of the 1998 IEEE International Symposium on Circuits and Systems*, 1998, pp. 537-540.

[117] C. Gerrish. (2014, 24.2.). *Military COTS Pros and Cons – Article* [Online]. Available: http://blog.rocelec.com/?p=1335#.Vs8IZ_mLRD8

[118] L. D. Alford Jr, "The problem with aviation COTS," *Aerospace and Electronic Systems Magazine, IEEE*, vol. 16, pp. 33-37, 2001.

[119] J. S. Gansler and W. Lucyshyn, "Commercial-Off-The-Shelf (COTS): Doing It Right," DTIC Document, 2008.

[120] L. Haines, "Technology Refreshment Within DoD," presented at the PROGRAM MANAGER, 2001.

[121] R. Taylor, "Situational Awareness Rating Technique(SART): The development of a tool for aircrew systems design," in *Situational Awareness in Aerospace Operations (AGARD)*, 1990.

[122] J. Brooke, "SUS-A quick and dirty usability scale," in *Usability evaluation in industry*, 1996, pp. 4-7.

[123] M. Nieminen and M.-R. Koivunen, "Visual Walkthrough: experiences," in *Special Interest Group on Computer Human Interaction (SIGCHI) Bulletin*, 1995, p. 3.

[124] S. Riihiaho, "User testing when test tasks are not appropriate," in *European Conference on Cognitive Ergonomics: Designing beyond the Product - Understanding Activity and User Experience in Ubiquitous Environments*, 2009, p. 21.

[125] P. M. Salmon, N. A. Stanton, G. H. Walker, D. Jenkins, D. Ladva, L. Rafferty, *et al.*, "Measuring Situation Awareness in complex systems: Comparison of measures study," *International Journal of Industrial Ergonomics*, vol. 39, pp. 490-500, 2009.

[126] E. P. Blasch and S. Plano, "JDL Level 5 Fusion Model: User Refinement Issues and Applications in Group Tracking," in *AeroSense*, 2002, pp. 270-279.

[127] M. R. Endsley, S. J. Selcon, T. D. Hardiman, and D. G. Croft, "A comparative analysis of SAGAT and SART for evaluations of situation awareness," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 1998, pp. 82-86.

[128] M. R. Endsley, R. Sollenberger, and E. Stein, "Situation awareness: A comparison of measures," in *Proceedings of the Human Performance, Situation Awareness and Automation: User-Centered Design for the New Millennium*, 2000, pp. 15-19.

[129] D. G. Jones and M. R. Endsley, "Can real-time probes provide a valid measure of situation awareness," *Proceedings of the Human Performance, Situation Awareness and Automation: User-Centered Design for the New Millennium*, 2000.

[130] M. Endsley and R. R. Hoffman, "The Sacagawea principle," *Intelligent Systems, IEEE,* vol. 17, pp. 80-85, 2002.

[131] C. Bolstad, A. Costello, and M. Endsley, "Bad situation awareness designs: What went wrong and why," in *Proceedings of the 16th World Congress of International Ergonomics Association*, 2006.

[132] M. R. Endsley, "Direct measurement of situation awareness: Validity and use of SAGAT," *Situation Awareness Analysis and Measurement*, vol. 10, 2000.

[133] P. Salmon, N. Stanton, G. Walker, and D. Green, "Situation awareness measurement: A review of applicability for C4i environments," *Applied ergonomics,* vol. 37, pp. 225-238, 2006.

[134] M. R. Endsley, "Situation awareness and workload- Flip sides of the same coin," in *7th International Symposium on Aviation Psychology* Columbus, OH, 1993, pp. 906-911.

[135] D. G. Jones and M. R. Endsley, "Use of real-time probes for measuring situation awareness," *The International Journal of Aviation Psychology,* vol. 14, pp. 343-367, 2004.

[136] T. Z. Strybel, K.-P. L. Vu, J. Kraft, and K. Minakata, "Assessing the situation awareness of pilots engaged in self spacing," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 2008, pp. 11-15.

[137] S. Liu, X. Wanyan, and D. Zhuang, "Modeling the situation awareness by the analysis of cognitive process," *Bio-Medical Materials and Engineering,* vol. 24, pp. 2311-2318, 2014.

[138] A. Beukel and M. Voort, "Driver's situation awareness during supervision of automated control-comparison between SART and SAGAT measurement techniques," 2014.

[139] J. Sauro. (2016, 19.3.). *Measuring Usability with the System Usability Scale (SUS)* [Online]. Available: http://www.measuringu.com/sus.php

[140] S. Frieze. (2015, 4.4.). *System Usability Scale: A Quick Usability Scoring Solution* [Online]. Available: http://satoriinteractive.com/system-usability-scale-a-quick-usability-scoring-solution/

[141] U.S. Department of Health and & Human Services. (2015, 4.4.). *Eye Tracking* [Online]. Available: http://www.usability.gov/how-to-and-tools/methods/eye-tracking.html

[142] K. Pernice and J. Nielsen, "How to conduct eyetracking studies," *Nielsen Norman Group, Fremont, CA,* 2009.

[143] M. R. Endsley and D. J. Garland, *Situation Awareness Analysis and Measurement*: CRC Press, 2000.

[144] C. Bolstad, "The Measurement of Situation Awareness for Automobile Technologies of the Future," A presentation to the Driver Metrics Workshop, Iowa, 2008.

[145] R. Virrankoski, *Wireless Sensor Systems in Indoor Situation Modeling II (WISM II): Final report* vol. 188, 2013.

[146] WISM II project video. (2013, 30.12.). *WISM II* [Online]. Available: http://www.youtube.com/watch?v=9v1fFIHRWGE

[147] ZeroC Inc. (2015, 16.12.). *Documentation Center* [Online]. Available: https://doc.zeroc.com/display/Doc/Home

[148] M. Korkalainen, P. Tukeva, M. Lindholm, and J. Kaartinen, "Hybrid Localization System for Situation Awareness Applications," in *3rd Workshop on Wireless Communication and Applications (WoWCA2012)*, Vaasa, Finland, 2012.

[149] H. Yigitler, R. Virrankoski, and M. S. Elmusrati, "Stackable Wireless Sensor and Actuator Network Platform for Wireless Automation: The UWASA Node," in *Aalto University Workshop on Wireless Sensor Systems, Espoo, Finland*, 2010.

[150] M. Bocca, O. Kaltiokallio, and N. Patwari, "Radio tomographic imaging for ambient assisted living," in *Evaluating AAL Systems Through Competitive Benchmarking*, ed: Springer, 2012, pp. 108-130.

[151] O. Kaltiokallio, M. Bocca, and N. Patwari, "A multi-scale spatial model for RSS-based device-free localization," *arXiv preprint arXiv:1302.5914,* 2013.

[152] M. Matusiak, J. Paanajärvi, P. Appelqvist, M. Elomaa, M. Vainio, T. Ylikorpi, *et al.*, "A novel marsupial robot society: towards long-term autonomy," in *Intl. Symposium on Distributed Autonomous Robotic Systems*, 2008.

[153] J. Vallet, O. Kaltiokallio, M. Myrsky, J. Saarinen, and M. Bocca, "Simultaneous RSS-based localization and model calibration in wireless networks with a mobile robot," *Procedia Computer Science,* vol. 10, pp. 1106-1113, 2012.

[154] Esri. (2013, 12.8.). *Tracking Server 10 - An Esri ® White Paper* [Online]. Available: http://www.esri.com/library/whitepapers/pdfs/tracking-server-10.pdf

[155] Esri. (2013, 12.8.). *ArcGIS® 10.1 for Server Functionality Matrix - An Esri ® White Paper* [Online]. Available: http://www.esri.com/library/brochures/pdfs/arcgis-server-functionality-matrix.pdf

[156] T. Lewis, *Critical Infrastructure Protection in Homeland Security - Defending a Networked Nation*: John Wiley & Sons Inc 2006.

[157] P. R. Garvey, R. A. Moynihan, and L. Servi, "A macro method for measuring economic-benefit returns on cybersecurity investments: The table top approach," *Systems Engineering,* vol. 16, pp. 313-328, 2013.

[158] Multinational Alliance for Collaborative Cyber Situational Awareness: Collaborative Cyber Situational Awareness (CCSA), "Information Sharing Framework (ISF) Released – 20 Nov 2013 (Version 2.4)," 2013.

[159] S. Tiilikainen and J. Manner, "Suomen automaatioverkkojen haavoittuvuus," Aalto yliopisto, Sähkötekniikan korkeakoulu 2012.

[160] L. Rummukainen, L. Oksama, J. Timonen, and J. Vankka, "Situation awareness requirements for a critical infrastructure monitoring operator," in *2015 IEEE International Symposium on Technologies for Homeland Security (HST)*, 2015, pp. 1-6.

[161] L. D. Strater, M. R. Endsley, R. J. Pleban, and M. D. Matthews, "Measures of platoon leader situation awareness in virtual decision-making exercises," DTIC Document, 2001.
[162] J. Timonen, "Situational awareness and visualization in a cyber environment and a C2 system of dismounted soldiers," Poster presentation, VizSec, Paris, France, 2014.
[163] R. E. Jones, E. S. Connors, and M. R. Endsley, "Incorporating the human analyst into the data fusion process by modeling situation awareness using fuzzy cognitive maps," in *12th International Conference on Information Fusion*, 2009, pp. 1265-1271.
[164] J. Annett, "A note on the validity and reliability of ergonomics methods," *Theoretical Issues in Ergonomics Science,* vol. 3, 2002.
[165] N. A. Stanton and M. S. Young, "What price ergonomics?," *Nature,* vol. 399, pp. 197-198, 1999.
[166] N. Stanton, P. M. Salmon, L. A. Rafferty, G. Walker, and D. Jenkins, *Human factors methods: a practical guide for engineering and design*: Ashgate Publishing, Ltd., 2005.
[167] J. A. Black and D. J. Champion, *Methods and issues in social research*: John Wiley & Sons, 1976.
[168] E. G. Carmines and R. A. Zeller, *Reliability and validity assessment* vol. 17: Sage publications, 1979.
[169] N. Golafshani, "Understanding reliability and validity in qualitative research," *The Qualitative Report,* vol. 8, pp. 597-606, 2003.

NOTIFICATION

Due to copyright laws the pages 84 – 255 have been removed.

Please contact the Library of the National Defence University
for a full printed version of this dissertation!

National Defence University
PL 7, 00861 HELSINKI

Tel. +358 299 800

www.mpkk.fi

ISBN 978-951-25-2994-0 (pbk.)
ISBN 978-951-25-2995-7 (PDF)
ISSN 2342-9992 (print)
ISSN 2343-0001 (web)

100 **Puolustusvoimat**
Försvarsmakten • The Finnish Defence Forces