Information engineering for supporting situation awareness of nautical traffic management operators

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Ellemieke van Doorn

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PhD thesis

Ellemieke van Doorn

Information engineering for supporting situation awareness of nautical traffic management operators

Dissertation

For the purpose of obtaining the degree of doctor
at Delft University of Technology
by the authority of the Rector Magnificus prof. dr. ir. T.H.J.J. van der Hagen;
Chair of the Board for Doctorates
to be defended publicly on
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by
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CHAPTER 1

INTRODUCTION

1.1 Inland waterway traffic management

Goods transportation on the inland waterways is vital for the Dutch economy. The position of the Netherlands and its rivers connecting her to the European hinterland make transportation by vessels technically possible and economically attractive. The Rhine, the busiest river in the world, flows from Switzerland through France and Germany and finds its way via different rivers in the Dutch delta towards the North Sea. Consequently, two of the five largest European ports are located in the Netherlands, i.e. in Rotterdam and Amsterdam. The port of Rotterdam is the largest seaport in Europe and eighth in the world in terms of transshipment volume. Rotterdam transships close to 450 million tons of cargo per year. Amsterdam, the fifth cargo seaport in Europe, transships approximately 100 million tons of cargo per year [1]. The transport of goods by water is, according to the statistics in 2017, 34% of overall goods transport in the Netherlands [2].

However, transportation on the inland waterways should not only be efficient, but also safe. The number and size of vessels on the Dutch inland waterways have increased over the past years, increasing the risks for accidents and congestion. At the end of 2013 an expansion of the Port of Rotterdam called “Second Maasvlakte” was put into service. With this expansion the container capacity of the port was doubled and the total capacity increased by 20% [3]

[4]. Consequently, more and larger container ships have transshipped goods into the Port of Rotterdam. The target of the Port of Rotterdam is to transport 45% of the containers to and from the hinterland by ship. This has led to heavier traffic on the Dutch inland waterways [5]. The same waterways are navigated by large container vessels, pushed convoys with four to six barges, and tankers transporting hazardous goods, as well as by, for example, dry-cargo freighters, small fisher boats, and recreational vessels.

Currently, local traffic management is used to support safe and efficient traffic flows at unsafe locations or bottlenecks in the waterway network. Vessel traffic service (VTS) is a form of local traffic management to prevent the emergence of dangerous maritime traffic situations within definite VTS areas. Typically, these are areas with a greater risk of unsafe traffic conditions because of the combination of high traffic intensities with complex infrastructure, such as complex waterway crossings or sharp turns. VTS consists of viewing and reviewing the local traffic situation, giving traffic information and if necessary giving traffic directions to skippers [6]. Other forms of local traffic management are mobile traffic control from a patrol vessel, anchorage ground regulation, and local traffic control for safe and efficient lock and bridge passages.

Local events, such as a collision between vessels, obstruction of a lock, or low water conditions, have consequences elsewhere in the waterway network. Consider, for example, the case where a collision between vessels results in leakage of dangerous cargo. If the waterway is closed, then skippers need to know whether they can take an alternative route as a best option, or better wait until the obstructed waterway is available again. In this dangerous case, water authorities may need to stop nearby pumping stations. Emergency services may want to know whether there is an empty vessel nearby, which can take over the cargo of the damaged vessel. However, if only local traffic management is applied, no one can get a comprehensive overview of the entire situation. Without this overview, the consequences of local events on the rest of the network cannot be managed, and skippers, water authorities and emergency services get no information to assess the situation and to make decision on the actions to be taken.

1.2 Nautical operational network management

To continue to support safe and smooth transportation now that traffic density and complexity have increased, it is important to oversee and manage traffic flows in the entire network. For this purpose, the Dutch waterway authority Rijkswaterstaat is giving growing attention to corridor traffic management on inland waterways. In line with this, Rijkswaterstaat is introducing a new traffic management operator role, called nautical operational network management (N-ONM). N-ONM operators control events and incidents on a corridor and provide relevant information about the situation to skippers, colleagues and emergency services. Towards this end, they need to have a clear mental picture of the situation in the controlled corridor. An example of such a corridor is the total of the main route and all alternative routes between Port of Rotterdam and Germany. N-ONM operators need to concurrently pursue multiple goals for water-, traffic-, and information management [7]:

- ***Contribute to maintain safe water levels***
  Although N-ONM is primarily a traffic management role, operators need to make sure that the measures they take do not endanger water barriers. This is especially relevant in cases where alternative routes contain locks. The usage of locks influences water levels. Water levels need to stay within defined lower and upper limits in order to prevent damage to dikes and floods. Ensuring safe water levels has the highest priority. Therefore, it might not be possible to direct all vessels towards an alternative route.
- ***Contribute to maintain sufficient clean water***
  In cases of water pollution, for instance as a result of a leak of cargo, measures such as placing an oil net might be necessary to ensure sufficient clean water. Decision making on the necessity and type of measures, however, requires careful considerations, since these measures might hinder safe and efficient traffic flows.
- ***Safeguard safe and efficient traffic flows***
  Operators are responsible for taking traffic measures to support safe and efficient traffic flows, such as setting up alternative routes, activating one-way traffic, or temporarily adjusting control regimes of bridges and locks.

- ***Avail reliable and useful information concerning a traffic corridor***
  N-ONM operators need to inform colleagues, skippers, water authorities, and emergency services about the current and expected situation at a traffic corridor.

Although N-ONM operators are responsible for a waterway corridor instead of a local vessel traffic service (VTS) area, they still use information systems which were developed for local traffic control. Some examples are given in Figure 1.1. An example of systems used by N-ONM operators are geographic information systems (GIS) displaying vessel positions and movements. An important type of information system for traffic management is IVS90, which displays detailed information about voyage, cargo and hull of vessels. Other relevant systems are GIS applications displaying waterway information, electronic logbooks, and meteorology and water management information systems, which provide operators with data on current and anticipated weather and water levels. The availability and arrangement of these systems depend on the concerned traffic management centers, which have resulted in different workstation designs.

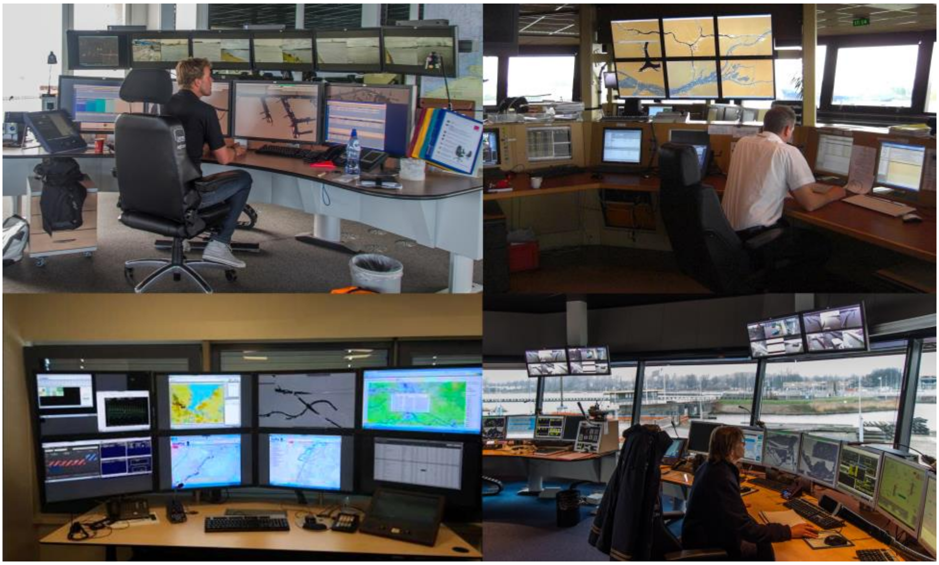

Figure 1.1 Examples of traffic management workstations at Rijkswaterstaat [8] [9]

1.3 Challenges of nautical operational traffic management and project initiation

While using traditional systems in the changed traffic situation, N-ONM operators experience difficulty to gain and maintain a sufficiently complete and correct mental picture of the controlled corridor. Current systems display detailed information about the present situation at several locations at the controlled corridor, such as information about vessels and their cargo in the different VTS areas. To gain a mental picture of the situation at the corridor, operators need to combine this information in their mind.

The mental picture of an operator about a dynamic environment is called situation awareness (SA). SA is defined as "*the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future*" [10]. In an earlier study, it has been observed that traffic management operators are finding it more and more difficult to mentally combine information from multiple information systems [11]. A lack of SA may occur due to the increase of the number, size, and diversity of vessels on the inland waterways. This development may lead to an increase in the number of critical traffic situations, which implies a higher risk in decision making. Growing traffic density also increases the amount of related data available to the operators, from which relevant data needs to be accessed. Another identified trend is an increased need for reliable and useful traffic information for management and third parties [11]. To fulfil this need, there has been an increase in the amount of information systems used by traffic management operators. To cope with these challenges, Rijkswaterstaat aimed to improve and unify traffic management working methods and wished to redesign the man-machine interactions in order to optimize operators' SA, workload, and task performance [6].

To cope with the above described societal problem, Rijkswaterstaat set up an innovation project, Vessel Traffic Management Centre of Tomorrow, to define a vision of future traffic management [6]. The aim of this project was to define a new vision on the traffic management services carried out by Rijkswaterstaat. Starting out with this objective, the work processes and tasks, responsibilities, and authorization of operators were defined. This formed the basis of defining new workstation and man-machine interaction designs. This PhD research has its roots also in the above described societal problem and was carried out parallel to the innovation project, as shown in Figure 1.2. The PhD research was used as input for the innovation project, while the innovation project was used to validate the knowledge generated in the PhD research project. Rijkswaterstaat did not put restrictions on this study in terms of methods to be applied or products to be delivered. The PhD candidate, however, was also a work package leader in the innovation project and in this role she was responsible for the workstation and man-machine interaction design. The framework innovation project has translated this functional design into a system architecture and various technical specifications.

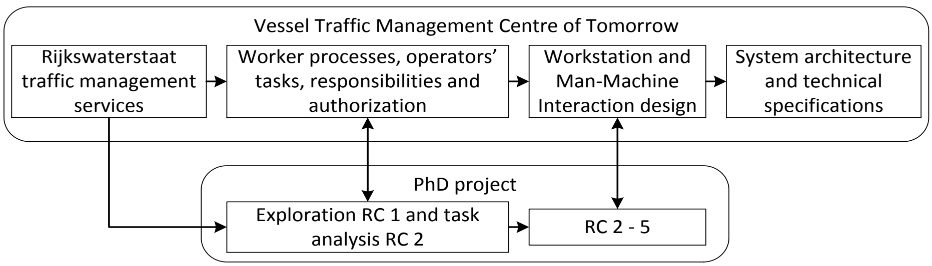

Figure 1.2 Relations between the Rijkswaterstaat project Vessel Traffic Management Centre of Tomorrow and this PhD research

1.4 Challenges of designing situation awareness support systems

Before we could address the societal problem presented in the previous section, we need a clear understanding of the meaning of SA in the context of the thesis. Various SA theories have been developed in the fields of air traffic control [12] [13], traffic operations [14] [15], aviation [16] [17] [18], and process control [19] [20]. Because N-ONM is a new form of traffic management, there is not yet a common understanding of SA for N-ONM. A critical review of existing SA theories is required to identify which of these theories are relevant for N-ONM and what the limitations of applying these theories in N-ONM context are. While SA exists within the operators' mind, a lack of SA is not simply related to the human operator. It is in the man-machine interaction that lack of SA arises. Information systems used in the field of N-ONM and similar contexts are complex information systems; they contain large sets of related information which change dynamically. Not all information that is available in the systems is also part of operators' required SA. Consequently, a theory is required which supports to take into consideration man-machine interactions when defining operators' SA. In the case of complex information systems, a rigorous study of SA requires to distinguish required SA knowledge from other relevant information.

If the required SA is known, then it still remains a challenge to evaluate whether operators have sufficient SA knowledge. SA is an abstract concept. It is not possible to observe or directly measure operators' SA, as it only exists within their mind [21]. Different SA measurement techniques are proposed in literature, but none of them have been applied in N-ONM context [22] [23] [24]. A review of existing techniques is required to select a suitable set of indicators to indirectly measure SA in N-ONM context. Besides, required SA depends on man-machine interactions. Therefore, simply comparing measurements of operators' SA knowledge is not sufficient to evaluate how well different system designs support operators' SA. A holistic understanding of SA is required when aiming to evaluate the effect of system designs on operators' SA.

Although it was recognized that current information systems do not sufficiently support operators' SA, it is not yet known what the deficiencies of these systems are in the above context. Existing approaches to identify deficiencies are based on the analysis of accident reports (e.g. [25] [26] [27]) or the assessment of operators' SA in simulated scenarios [28]. No N-ONM accident reports or N-ONM simulators were available for conducting our research. Others suggest to use observational research, but several researchers also indicate that the reliability of this approach is questionable [29] [30]. Because existing approaches were not suitable in N-ONM context, instead a different approach needed to be developed. The approach was supposed not only to support the identification of deficiencies of complex information systems, but also to provide input for a systematic design approach to overcome these deficiencies.

In the field of human-computer interactions, designers commonly use user-centered design (UCD) methods [31]. A wide range of UCD methods is described in literature, but it is unclear which methods are most applicable when designing complex information systems for N-ONM operators. A wide range of literature deals with how to design UIs to better support operators' SA. For example, Endsley et al. developed some general principles on how to present information to operators to enhance the operator's SA [32]. Other studies suggest methods to enhance operators' SA in a specific context. For example, for military aviation it is recommended to implement functions which visualize the consequences of operators' actions [33]. For air defense, information clustering and case-based reasoning are proposed to enhance operators' SA [34]. In the field of border surveillance, it is suggested to integrate data from different sensors into one single system to develop a common picture of the situation in the controlled environment [35]. All of these studies, however, dealt with SA in a different context than nautical traffic management or only provide general guidelines. They did not provide specific insight into which deficiencies of complex information systems were overcome by the proposed solutions. It therefore is unclear whether these solutions can be decontextualized. Which methods and UI concepts are suitable to be used in N-ONM context, therefore, is not known.

The UIs of complex information systems need to support human information processing to support operators in understanding the nature or meaning of the presented information. Therefore, design of UIs of complex information systems requires a systematic approach to model and specify relationships between information elements. Several systematic approaches, like formal modeling techniques, to handle large sets of information are developed in the field of information engineering (IE). Formal modeling techniques make it easier to design manageable, consistent, and reliable complex systems [36]. They, for example, have been applied to specify design rules to ensure consistency between UI components [37] [38]. Existing IE approaches, however, have primarily tended to support the design and specification of the use of information in systems. They did not explicitly consider issues of human information processing. It is unclear how IE can be used to support the analysis of human-system interactions and model the intricate relations between information elements and operators' tasks with the system. Specifying these relations is essential to capture the effect of information visualization on operators' SA, performance, and workload.

1.5 Scientific challenge, objective, and research approach

There is no clear standpoint in the current literature concerning how IE contributes to enhance systems' ability to support SA. The research hypothesis is that combining UCD with an IE approach will aid designers in designing better SA support. We assume that better SA support systems will enhance operators' ability to gain and maintain SA. Several researchers addressing SA support systems propose to use IE methods to specify system behavior in varying context, such as [39] [40] [41]. These contributions, however, mainly consider cases of varying input or output devices, or address system behavior in a limited amount of environmental conditions, such as geographic location or noise and light conditions. As far as we know, no research has addressed how formal modeling of interrelationships of large amounts of dynamic information entities aids designing SA support systems.

This research contributes to the aggregation of knowledge of how an IE approach aids designers in the analysis and design of human-system interactions to support SA. The aim of this thesis was to develop methods and design principles for improving operators' SA in complex information systems. The practical case of N-ONM operators experiencing difficulties to gain and maintain required SA was used to aggregate new knowledge and to validated developed methods and the effects of proposed design principles. The main question in our practical case study was how to enhance systems' ability to support SA of nautical traffic management operators to better support operational network management.

The scientific objectives of this study are to (i) gain understanding into causes of operators' lack of SA when working with complex systems, (ii) generate new knowledge on how to identify deficiencies of supporting SA and how to design UIs of complex systems that will support high levels of SA, and (iii) consolidation of the knowledge to ensure its relevance in a broad range of command and control environments. We identified several knowledge gaps, which needed to be addressed prior to answering our main research question:

Q.0. *How combined application of user-centered design and information engineering principles can enhance operators' situation awareness and* *support operators' task performance in nautical traffic management and similar contexts?*

We decomposed the main research question into the following working research questions:

Q.1. What defines required situation awareness in nautical operational network management context?

Q.2. What are the deficiencies of current systems in supporting situation awareness of nautical operational network management operators?

Q.3. Does combining user-centered design with an information engineering approach aid the analysis and design of user interface concepts that overcome identified deficiencies?

Q.4. Does the operationalization of the developed user interface concepts for complex information systems result in a functional design?

Q.5. Does the proposed IE approach aid to enhance systems' ability to support operators' situation awareness, task performance, and workload?

We addressed these questions in four related research cycles (RCs) as shown in Figure 1.3. Each RC followed a structured design methodology as proposed by Horváth [42] [43].

The first two RCs addressed sub-question Q.1. (RC 1) and Q.2. (RC 2) and were investigated based on 'Research in design context' methodology. This methodology supports our goal to generate a better understanding of the studied phenomenon (i.e. lack of operators' SA) and is based on the knowledge and research methods of design related principles [43]. Examples of design related research methods which we applied are user observations and cognitive task analysis. RC 1 was an incomplete research cycle, which only addressed the exploration of research question 1. In order to define required SA, we developed an analysis scheme that combines tested existing theories on SA to study required SA in a holistic matter. This scheme was complemented with a method to syntactically and semantically process cognitive task analysis and observational research data to identify deficiencies of current support systems in RC 2. To validate the developed analysis scheme and method, we applied them in our case study to detect and categorize deficiencies of current SA support systems in N-ONM context.

The third RC used 'Design inclusive research', which enables knowledge generation by involving design as research means [42]. Design steps were used to create new opportunities for generating knowledge about designing complex information systems to support operators' SA, after which the design prototype was used to validate the generated knowledge. The aim of our third RC was to use the aggregated knowledge of the previous RCs together with UCD and formal modeling methods of IE to develop three new UI concepts. Each concept addresses one of the identified groups of deficiencies. We applied the proposed UI concepts in N-ONM context to investigate whether operationalization of the concepts results in a functional design. For this purpose, we implemented the conceptualized UIs in an N-ONM workplace simulator and demonstrated their feasibility and applicability.

The fourth RC was based on 'Operative design research'. This methodology uses designs to answer research questions that emerge from practice in a way that it informs practice [42]. In this RC, we used the N-ONM workplace

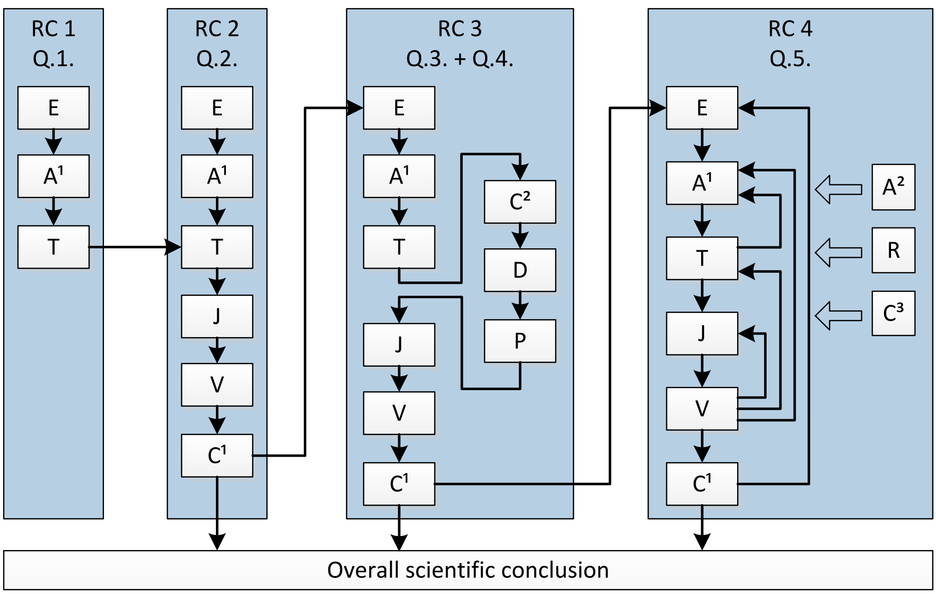

Figure 1.3 Procedural implementation of the applied research methodology, in which: E = Exploration, A^1 = Assumptions, T = Theorizing, J = Justification, V = Validation, C^1 = Consolidation, C^2 = Conceptualization, D = Design, P = Prototyping, A^2 = Aggregation, R = Reflections, C^3 = Confirmation

simulator, developed in the previous RC, to test the usability and the effect of the UI concepts on operators' SA, task performance, and workload. As a first step, we used the simulator environment to test the usability of the concepts with 12 subject-matter experts and 20 N-ONM operators. Secondly, a within-subject design was used to study the effects of the UI concepts on operators' SA, task performance, and workload by investigating differences in accuracy, timeliness, and completeness of communication and operators' actions. In addition, SAGAT [24] was used as a method to measure operators' SA and Raw NASA TLX [44] was used to measure operators' experienced workload.

1.6 Thesis outline

In Chapter 2 we summarize the findings of the literature study, in which we explored the knowledge domains that are relevant for the different research cycles. Synthesis of the existing knowledge was used to define required SA. An analysis scheme to study required SA in complex information systems context was derived from the literature study.

The analysis scheme presented in Chapter 2 was applied in Chapter 3 to structure information elicitation to identify deficiencies of SA support systems. The resultant information elicitation process is based on syntactic-semantic processing of cognitive task analysis and observational research data. This approach was used to identify deficiencies of supporting SA of N-ONM operators.

In Chapter 4 we discuss how combined use of UCD and IE methods aid to overcome the identified deficiencies. For this purpose, we addressed the deficiencies from an IE point of view and defined three IE-based user interface concepts. These concepts were implemented as prototypes in a workplace simulator for validation of the feasibility of the concepts.

Validation of the proposed IE approach is addressed in Chapter 5. For this purpose, the usability of the UI prototypes and their effects on operators' SA, task performance, and workload are addressed. Results of usability and effect testing aided to identify whether the prototypes produced results as expected by the theories underpinning them. If the outcome of this testing is positive, than we can assume that underlying concepts and the proposed IE approach result in a positive outcome as well.

In Chapter 6, we answer the main question of this work: 'How combined application of user-centered design and information engineering principles can enhance operators' situation awareness and support the task performance of operators in nautical traffic management and similar contexts?'. We reflect on the research project and the findings. For N-ONM context specific we sketched up potential strategies for UI design to better support operators' SA when further introducing N-ONM in Dutch nautical traffic management centers.

1.7 Own publications related to the topic of the thesis

This thesis is based on the following publications.

[a] Van Doorn, E.C., Horváth, I. and Rusák, Z. (2014) 'A systematic approach to addressing the influence of man-machine interaction on situation awareness' in TMCE 2014: Proceedings of the 10th International Symposium on Tools and Methods of Competitive Engineering, Budapest, Hungary, Vol.1, pp. 109 – 120.

[b] Van Doorn, E.C., Horváth, I. and Rusák, Z. (2015) 'Combined use of cognitive task analysis and observational research data to identify deficiencies of support for situation awareness' in HFES 2015: Proceedings of the Human Factors and Ergonomics Society 59th annual meeting, Los Angeles, USA, pp. 1717 – 1721.

[c] Van Doorn, E.C., Rusák, Z. and Horváth, I. (2017) 'A situation awareness analysis scheme to identify deficiencies of complex man-machine interaction', International Journal of Information Technology and Management, Vol. 16 No. 1, pp. 53 – 72.

[d] Van Doorn, E.C., Horváth, I. and Rusák, Z. (2017) 'Information engineering for developing and testing coherent, integrated and context dependent user interfaces', Cognition, Technology & Work, Vol. 19 No. 2 – 3, pp. 375 – 397.

[e] Van Doorn E.C., Horváth, I. and Rusák, Z. (in preparation) 'Validation of three information engineering approaches of user interface design to improve situation awareness support', Journal of Human-Computer Studies.

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CHAPTER 2

Research cycle 1

SITUATION AWARENESS IN NAUTICAL TRAFFIC MANAGEMENT AND SIMILAR CONTEXTS

In the introduction, we sketched the importance of nautical operational network management (N-ONM) operators, who control events and incidents on a corridor and provide relevant information about the traffic management environment to colleagues, skippers, water authorities, and emergency services. N-ONM operators, however, currently experience difficulty to gain and maintain sufficient situation awareness (SA), which limits the effectiveness of N-ONM. A first step to overcome this problem is to investigate what the required SA of N-ONM operators is. This chapter presents a literature review to better understand SA as a construct and to identify SA theories and system design methods which can be applied in the N-ONM context. Section 2.1 introduces relevant knowledge domains for a holistic study of SA. In Section 2.2 the N-ONM practice is compared to other command and control practices to decide whether theories developed in these environments can be considered relevant for N-ONM. Existing theories on SA and its relations with workload and performance are discussed in Section 2.3. An introduction to human information processing is given in Section 2.4. Section 2.5 discusses aspects of system design for SA support. The knowledge derived from the literature review is discussed in section 2.6.

2.1 Towards a holistic study of situation awareness

Although the observed societal problem is operators' lack of SA, the goal of improving operators' SA is not unambiguous. SA is a construct. It is a theoretical concept which cannot be directly observed or measured. If a loss of SA is identified, this is because operators' task performance was classified as inaccurate. Without a holistic understanding of SA, this can easily result in a focus on the operator who lost SA [1]. SA assessment, however, does not solely depend on the operators' abilities and efforts.

Indeed, the construct of SA has been addressed by researchers of many knowledge areas, such as Engineering (6615 scientific documents), Computer Science (5308 scientific documents), Mathematics (1958 scientific documents), Physics and Astronomy (1506 scientific documents), Social Sciences (1495 scientific documents), Materials Science (1027 scientific documents), Medicine (787 scientific documents), Earth and Planetary Sciences (718 scientific documents), Energy (460 scientific documents), Psychology (380 scientific documents), Decision Sciences (380 scientific documents), and Environmental Science (258 scientific documents) [2]. There is a large body of literature addressing SA and this number is still increasing, see Figure 2.1. It is undoable to evaluate all scientific literature addressing SA. Therefore, a reasoning model has been devised to structure our literature review, see Figure 2.2.

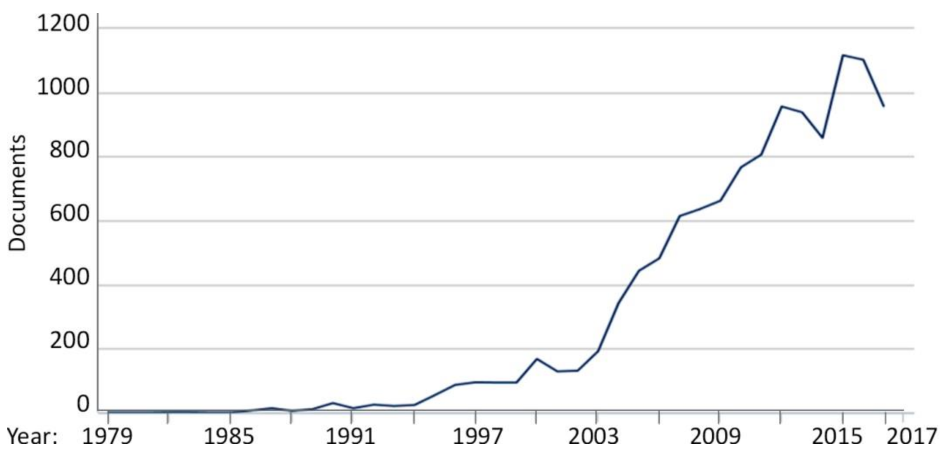

Figure 2.1 Amount of documents found at scopus.com when searching for documents that contain "situation awareness" or "situational awareness" in the abstract, title or keywords [2].

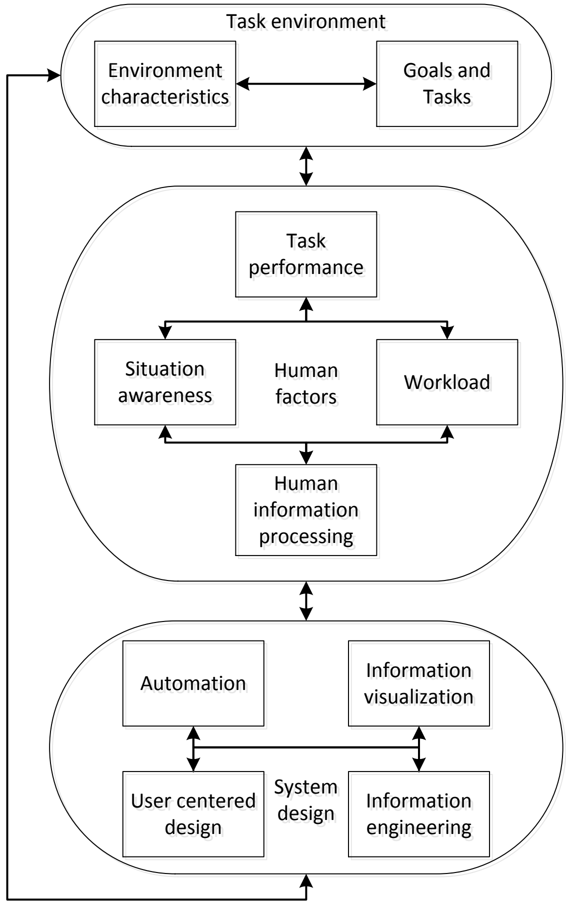

Figure 2.2 Reasoning model used to structure the literature review

As reflected by the knowledge areas that addressed SA, SA is related to (i) system design (e.g. engineering, computer science), (ii) human factors (e.g. social sciences, psychology), and (iii) task environments (e.g. medicine, energy).

System design:

The objective of our research is to study system design related to designing complex systems to support operators' SA. System design is commonly addressed from either an engineering point of view or from a human-system interaction point of view. Information engineering (IE) is commonly used when addressing system design from an engineering point of view. IE is a set of analysis and design techniques used to model and specify system logics.

User-centered design (UCD) addresses system design from a human-system interaction point of view. UCD is a set of design processes that support designers to analyze the behavior of users as they use products and consider this insight in every stage of the design process.

Human factors:

SA is one of the fundamentals of human factors research. In human factors research, SA is often addressed in relation to mental workload, which is another fundamental of human factors research. Indeed, the classic work 'Handbook of Human Factors and Ergonomics' contains a chapter named "Mental workload and situation awareness" [3]. Searching for documents that contained both "situation awareness" and "workload" in the abstract, title or keywords resulted in 679 scientific documents [2]. Both SA and mental workload have a significant impact on human-machine system performance [3]. Searching for documents that contain both "situation awareness" and "performance" in the abstract, title or keywords results in 1640 scientific documents, while 411 documents are found when searching for "situation awareness" AND "workload" AND "performance" [2]. The relation between these three human factors fundamentals therefore seems highly relevant in a holistic study of SA.

Task environment:

Operators' SA is the operators' mental picture of the situation in the dynamic task environment. The interaction of the human with his environment and the influence of the environment on operators' goals and tasks direct operators' SA. When studying SA, it is therefore relevant to understand the characteristics of the task environment and how they relate to operators' goals and tasks. In our research, we are interested in understanding SA in relation to operators who remotely control an environment using complex information systems. Theories developed in environments where operators rely on direct perception, such as road users relying on direct vision, are less relevant.

These different knowledge areas are not stand-alone. Systems can be used to automate operators' (sub)tasks, whilst automation of tasks and information visualization influence human information processing. The human information processing influences operators' SA and workload, which in turn influence operators' task performance. Operators' main task in command and control environments is to control the environment. Task performance thus influences the environment. Characteristics of the task environment on the other hand influence operators' SA, workload, and human information processing. In cases of operators using complex information systems, the systems themselves are an important characteristic of the task environment.

All topics introduced in this reasoning model are discussed in the rest of this chapter. These topics are all complex topics. In this thesis, we do not aim to provide a complete overview on the state of the art knowledge on these topics. Instead, we aim to provide an introduction to the different knowledge areas which are relevant for understanding our research study.

2.2 Task environments relevant to nautical traffic management

Operator's SA is considered to be important in a broad range of command and control tasks. The term is widely used in commercial and military aviation [4] [5] [6], air traffic control [7] [8], process control (i.e. operators controlling industrial processes, such as power plant control room operators) [9] [10], and traffic operations [11] [12]. In the fields of aviation, air traffic control, and process control various theories of SA have been developed. Although SA plays an important role in nautical traffic management, it has been addressed sufficiently neither from a theoretical perspective, nor from a practical one so far.

SA theories developed in aviation, air traffic control, and process control are considered generic across many different dynamic task environments [13] [14]. These theories are based on the assumption that SA is especially relevant in dynamic environments, where the environment state develops both with and without the operator's actions [6] [8]. Consequently, as Endsley concludes, operators are dependent on an on-going up-to-date analysis of the environment [13]. In nautical traffic management, operators influence the situation by providing information to the skippers and through traffic management measures. Besides, situations evolve due to skipper's actions and environmental factors like weather conditions. Both skippers and weather conditions are unpredictable. An on-going analysis of the environment thus is necessary in traffic management context as well. Similar to aviation, air traffic control, and process control, N-ONM operators actions depend on the situation and operators require predictions and forecasting for accurate task performance. In aviation, air traffic control, and process control contexts, predictions and forecasting focus on near future [13]. N-ONM operators, however, require more long term predictions and forecasting. The obstruction of locks and waterways can take days or weeks and alternative routes may only be relevant for skippers if obstructions on their current route will take more than a day.

A second important characteristic of aviation and air traffic control environments is that operators typically pursue multiple goals simultaneously. To do so, they need to carry out multiple tasks, which are competing for an operator’s attention and that require time-constrained decisions and actions [9]. SA is the foundation for their decision making and actions [15]. Kaber and Endsley argued that process control and aviation share these characteristics [9]. Operators working in traffic management environments also pursue multiple goals simultaneously. They are responsible for (i) safe water levels, (ii) sufficient clean water, (iii) safe and efficient traffic flows, and (iv) availability of reliable and useful information. These four main goals cannot be addressed separately, as they influence each other. For example, time-constrained measures to ensure safe water levels, such as limiting the use of locks, can have a negative effect on safe and efficient traffic flows. Especially, if operators do not provide timely and accurate information about these limitations to the skippers of vessels using the concerned waterways. A complicating factor for N-ONM is that the goals with the highest priority are only indirectly related to their task performance: water management and water quality goals have the highest priority, while operators’ tasks are all related to traffic management and information distribution. This makes it even harder for N-ONM operators to accurately pursue the multiple goals simultaneously than it is for other command and control operators.

Due to the above mentioned similarities, aviation, air traffic control, and process control are considered similar contexts to nautical traffic management. Theories relevant to these contexts are taken into consideration, while bearing in mind the relevant differences.

2.3 Human factors related to situation awareness support

The concepts of SA, workload, and task performance are intricately intertwined. SA and mental workload make use of the same cognitive processes, which capacities are limited [16]. A higher level of workload means that more attention is needed for performing tasks and less is left for maintaining SA. Then again, SA could be improved by working harder [3]. Cognitive overload, under-load, and low situation awareness can have a negative effect on operators' task performance. The combined use of the SA and mental workload construct can help to understand human-system performance [16].

2.3.1 SITUATION AWARENESS KNOWLEDGE

Published in 1995, Endsley's theory is the most commonly used theory of SA in aviation, air traffic control, and process control contexts [17] [18] [19]. The following definition was proposed: "*Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in near future*" [13]. A distinction in levels of SA is used [13]:

Level 1 SA: Perception of the elements in the environment

Level 2 SA: Comprehension of the current situation

Level 3 SA: Projection to future status

Level 1 SA is defined as *"to perceive the status, attributes, and dynamics of relevant elements in the environment"* [13]. Level 2 SA is described as "*Comprehension of the situation is based on a synthesis of disjoined Level 1 elements. Level 2 SA goes beyond simply being aware of the elements that are present (…)"* [13]. From these descriptions it remains unclear whether "simply being aware of the elements" is part of Level 1 SA or Level 2 SA? If data is perceived, this does not mean that an operator is also aware of the elements, and thus that the data is part of an operators' SA knowledge. Endsley, however, proposes that SAGAT, a method to measure operators' SA, should include queries about all operator SA requirements, including Level 1 (perception of data) [20]. At using SAGAT, operators are asked about their awareness of developed queries, such as "Enter aircraft callsign" and "Enter aircraft altitude" [20]. If Level 1 SA is to be part of SAGAT queries, than we conclude that Level 1 SA is not only about perception of elements, but also about being aware of the elements. Examples of Level 1 SA SAGAT queries are information elements, such as 'Aircraft type', 'Altimeter setting', and 'Assignment given' [21]. Examples of Level 2 SA are all about relations between information pieces, such as 'Location of nearest capable airport for aircraft type / emergency', 'Number / timing aircraft on routes', and 'Time / distance aircraft to airport' [21]. Examples of Level 3 SA are all related to projections, predictions or impact, such as 'Projected aircraft route', 'Predicted changes in weather', and ' Impact of potential route changes' [21]. To our understanding, this results in the following descriptions of the levels of SA:

Level 1 Perceptual knowledge: the factual knowledge of elements in the current situation, without understanding relations between elements. For example: location of vessels, or names of vessels.

Level 2 Comprehended knowledge: a deeper understanding of the meaning and relationships of knowledge in the current situation. For example: awareness of which of the service vessels is closest to an incident.

Level 3 Projected knowledge: insight in future activities of the elements in the environment and understanding of future environment dynamics in relation to operator's goals. For example: awareness of how long it will take for a service vessel to navigate towards an incident location.

Operators' SA knowledge consists of the combination of knowledge on all three levels. Sufficiently correct and complete SA knowledge is required for correct decision making [13]. SA knowledge is the understanding of dynamic information associated with operator' goals and does not include more static knowledge stored in long-term memory [20]. Command and control operators commonly require understanding the current and prospective meaning and relationships of large amounts of information about their dynamic environment. Due to the need to have such a large amount of information mentally available, the main challenge of operators is his/her ability to locate and process such information [20].

SA knowledge exists in an operators' mind only. It is an abstract construct, which cannot be directly observed. Many SA measurement techniques have been developed for assessing operators' SA, but only two of the commonly used techniques are sufficiently validated [22]. The most commonly used and properly validated SA measurement technique is the situation awareness global assessment technique (SAGAT) [20]. SAGAT proposes questioning operators about their SA knowledge at randomly selected times. During questioning, the situation is put on hold and system displays are blanked. SAGAT proposes to include queries about all operator SA requirements, covering the three levels of SA. The main challenge in applying SAGAT is to develop a relevant and sufficiently elaborated set of queries. A limitation of SAGAT is that it requires freezing a situation and blank system displays. It therefore can only be used in simulator environments. Another validated SA measurement technique is the situational awareness rating technique (SART) [23]. SART is a self-rating technique. When using SART, operators are asked to rate their level of SA knowledge on ten domain-independent aspects. SAGAT and SART are fundamentally different measurement techniques. The main differences are presented in Table 2.1. Instead of applying a specific SA measurement technique in each research setting, it is advised to use successful techniques in parallel. Besides SAGAT and SART, it might be useful to include performance measures and observer rating techniques as well [22].

2.3.2 SITUATION AWARENESS ASSESSMENT

The processes of achieving, acquiring or maintaining SA knowledge are referred to as SA assessment [13]. Guided by mental models (i.e. a set of knowledge which forms a conceptual analogue of the external world to understand and predict the environment), operators process input from information systems for SA assessment [7]. SA is the foundation for their

Table 2.1 Differences between SAGAT and SART

	SAGAT	SART
Type of questions	Domain-specific	Domain-independent
Moment of questioning	During freeze of task execution	After task execution
Type of method	Questioning tool	Self-rating
Type of measurement	Measuring what information is part of SA knowledge?	Measuring SA on a scale from low to high

decision making and actions which influence the state of the environment [15]. When the gained SA knowledge conflicts with the applied mental models, this triggers the operators to update their mental model [24]. The SA model of Feng et al. can be used to describe how the different levels of SA knowledge together form the steps of SA assessment when using a system as representation of the physical world [25]:

- A software tool represents the knowledge of the physical world, such as locations on a map with necessary descriptive attributes.
- An operator perceives entities representing an object in a situation with its attributes and events containing information about when, where, who, what and why of a situation.
- An operator combines the perceived disjoined information, for comprehension of the current situation.
- An operator uses trends and prior knowledge to project out the current situation to predict future states of the environment.
- Based on these projections, the operator decides upon actions to take.
- These actions influence the state of the environment.
- Perception and comprehension of these changes helps the operator to reflect on his own projections and decisions, allowing an operator to update his mental model and related projection strategies.

Figure 2.3 shows a schematic description of SA assessment from a remotely controlled context. Traditional information systems mainly support perception of pieces of information. More advanced or context-aware support systems use computational SA assessment to directly support comprehension of a given situation, and to provide projected SA knowledge or decision support to the operators [25] [26] [27] [28].

2.3.3 FACTORS INFLUENCING SA ASSESSMENT

As visualized by Endsley's model of SA in dynamic decision making (see Figure 2.4) individual, task, and system factors influence an operator's SA knowledge. Durso and Sethumadhavan [29] and Adams et al. [30] pointed out that a person's SA is influenced by attention and working memory capacity, which are partly innate but can be trained. They showed that experience and training help to develop schemata of prototypical situations in long-term memory stores, through which limitations of attention may be circumvented to some degree by the development of automaticity. Patrick and Morgan argued that SA is largely affected by a person's goals, objectives, and expectations, which influence how attention is directed, how information is perceived, and how it is interpreted [31]. These contributions showed that human information processing mechanisms influence SA assessment, decision making, and performance of actions [13]. If we aim at improving operators' SA, we therefore need a basic understanding of human information processing, see also Section 2.3.6.

Endsley [13] and Wickens [6] argued that a higher task complexity will increase the amount of mental workload required to gain and maintain SA. They consider a high mental workload as a stressor. Endsley reasoned that stress reduces working memory capacity and retrieval of information, and negatively influences SA assessment. Under stress operators tend to focus their attention on a limited number of dominant pieces of information. They tend to (i) arrive at a decision without exploring all available information, (ii) put more attention to negative information, and (iii) have a more scattered and poorly organized scanning of stimuli [13]. While focusing on negative information can be a positive strategy, as negative information is a course of problems to be solved, this may also cause operators to miss other relevant

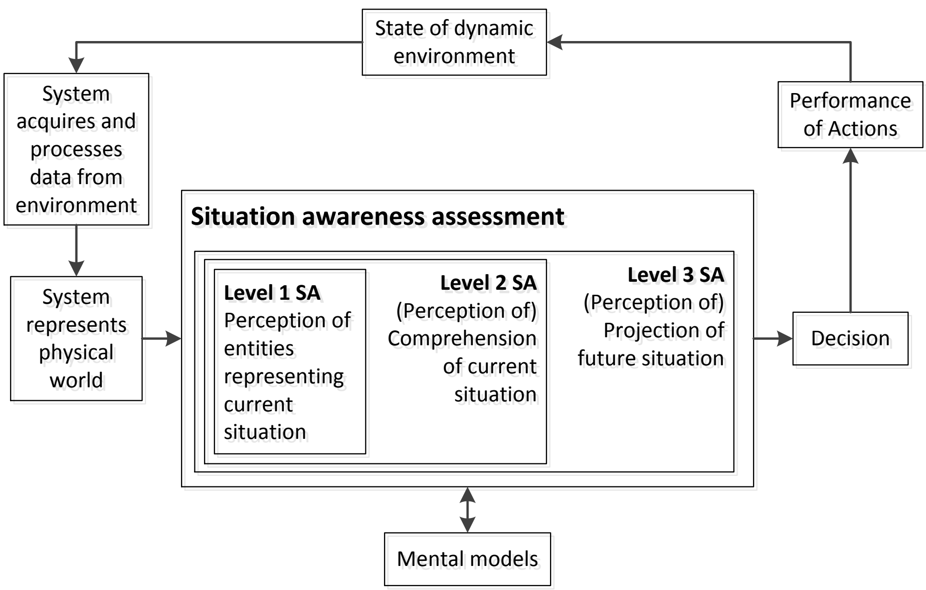

Figure 2.3 Model of SA assessment, developed based on the SA model of Feng et al. [25] and Endsley's model of situation awareness in dynamic decision making [13]

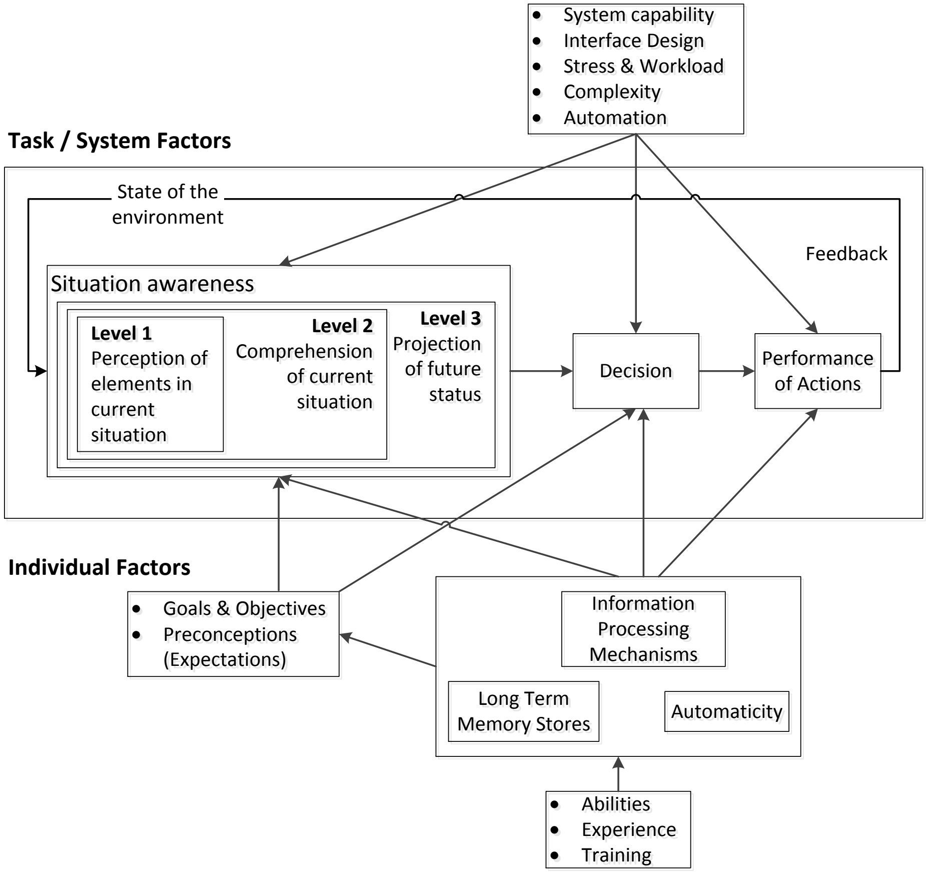

Figure 2.4 Model of situation awareness in dynamic decision making [13]

information. Insight in the relations between SA and workload therefore is required, which is addressed in Section 2.3.5.

Which information operators focus on, depends on the systems used to retrieve information. Thus, to which degree the working memory decrements affect SA. Endsley pointed out that system factors influencing SA are “*the capability of systems for deriving needed information, the effect of system complexity on SA, the effectiveness of the user interface for providing rapid access and understandability of needed information* (…) *and the effect of automation on SA*” [32]. Automation can be used to relieve operators from a part of the workload, but it can also result in a loss of the operators’ SA due to human-out-of-the-loop problems [33]. The effect of automation on SA is discussed in more details in Section 2.4.3.

Current theories identify individual, task, and system factors as factors which influence operators' SA. They, however, address these factors separate from each other. They overlook the importance of man-machine interaction. Individual characteristics, such as color blindness, only negatively influence an operator's SA if the system interface is not suitable for color blind people. The influence of individual abilities on the SA assessment thus also depends on the context of man-machine interaction. Endsley argued that system design influences situation awareness in terms of: (i) the degree to which the system acquires all the needed information from the environment, (ii) the degree to which the system displays all the relevant information to the operator, (iii) the way information is processed and presented, and (iv) the degree to which the operator is able to process all the relevant information, taking into consideration perception, attention, and working memory constraints [13]. As such, Endsley took individual factors like information processing into consideration when discussing system factors influencing SA. Her model of SA, see Figure 2.4, however, does not show these relations. Based on Endsley's commonly applied theory it remains unclear how the relations between these factors are related to SA knowledge, SA assessment, and required SA.

2.3.4 REQUIRED SITUATION AWARENESS

Smith and Hancock define SA as the invariant defining what must be known and done to fulfill the operator's goal [34]. They regard knowledge about the environment and the directed action within that environment as products of SA. They exclude SA knowledge and the assessment process from their definition of SA. Although this narrow definition is not in line with our striving for a holistic approach, it helps to better understand loss of SA. Smith and Hancock state that examination of higher of lower degrees of SA or loss of SA remains impossible until an external goal and criteria for achieving SA are specified [34]. As the goals of an operator are related to his task environment, they conclude it is impossible to understand SA without a viable understanding of the interaction between operators and their task environment. Their definition of SA describes what in our viewpoint is called the required SA.

Only if required SA to achieve operators' goals is properly specified, examination of higher or lower degrees of SA or loss of SA is meaningful. Cognitive task analysis (CTA) has been proposed as a means to determine SA requirements for a wide range of SA dependent task domains, for example aviation [4], aviation maintenance teams [35] and traffic operations [11]. Endsley and Jones [36] provided a detailed description of how to use task analysis to define SA requirements. "[The approach] *seeks to determine what dynamic information operators need to know in order to make decisions without focusing on how the operator currently obtains that information*" [36]. They proposed that "*The information requirements should be listed without reference to technology or the manner in which the information is obtained*" [36].

Evaluation of existing SA theories shows that operators' required SA needs to be properly specified in order to be able to examine loss of SA. Current methods proposed to define required SA, however, define 'perfect SA', [4], seeking to determine a total set of information that operators ideally like to know to meet their goals [21]. Researchers applying CTA strive to be technology free to allow the design and evaluation of new systems that seek to improve SA [4] [21]. Such an approach to defining required SA is suitable when it is to be analyzed to what extent a system supports operator's SA and when a comparison of systems with regard to the level of SA support is required. It does not specify, however, when an operator's SA is sufficient instead of ideal. Knowing more does not necessarily mean having better SA. In the cases in which operators work with complex systems, which present large amounts of data, it is impossible for operators to memorize all relevant information, and it may not be necessary. Current approaches to define required SA do not take into consideration that the use of systems can help to reduce the amount of information which operators need to memorize. Evaluation of support of SA requires insight into whether the current support systems enabling operators to gain and maintain sufficient SA. If not, it requires identifying causal deficiencies of current support of SA; i.e. those deficiencies which hinder operators in gaining and maintaining required SA. Deficiencies which hinder operators in gaining and maintaining perfect SA, but do not hinder operators in gaining and maintaining required SA are considered acceptable. Deficiencies which cause operators to have a lack of SA however are intolerable deficiencies. Theories which define required SA as 'perfect SA' do not differentiate between intolerable and acceptable deficiencies for current support of SA and therefore do not support evaluation of loss of SA.

In order to distinguish required SA from 'perfect SA', it is important to differentiate operator's SA knowledge from required SA. Current theories address SA as if the required SA knowledge is static for a specific task or goal, independent of context factors such as the operators' characteristics and the systems user interface (UI). Adams et al. do address the interrelation between SA knowledge and SA assessment process. They define this relation as the "cyclical resetting of each by the other", describing how the process of information processing to build up new knowledge is influenced by the operator's current knowledge [30]. Although useful to identify the difference in situation awareness in different circumstances, it does not provide insight in whether there is a lack of situation awareness. Current theories imply that by simply analyzing the operator's knowledge of the dynamic situation, one can say whether this knowledge fits the required knowledge for the tasks at hand. The first step, however, should be to define required SA.

2.3.5 MENTAL WORKLOAD

Workload for control room operators mainly consists of cognitive task load. Cognitive load for operators depends on the percentage of time occupied, the level of information processing, and the number of task-set switches [37]. For percentage of time occupied, people should not be occupied more than 70 to 80 percent of the total time available [38]. The work of Rasmussen [39] can be used to define the level of information processing. The level of information processing is high for knowledge-based tasks, moderate for rule-based tasks and low for skill-based tasks. Switching attention between tasks takes time, and task execution is slower after task switches than when the same task can be carried out for a longer time span [40]. The cognitive task load is high when the percentage time occupied, the level of information processing, and the number of task-set switches are high. A higher level of information processing and/or a larger amount of task-set switches also may cause the time occupied to increase [31]. If the cognitive task load is too high, then the task demands may exceed the capabilities of the operators. A high cognitive task load can result in an increase in fatigue and cognitive overload, which can have a negative impact on performance [41]. A low cognitive task load on the other hand can result in boredom and under-load, which also may negatively affect performance [42]. Table 2.2 combines insights on mental workload and SA in order to describe possible relations between SA, workload, and task performance.

Table 2.2 Possible SA and workload relations, from combining [37] and [43]

Possible extremes	Problems	Resultant situation
Situation awareness ***Low*** Workload ***Low***	Under-load: Operator is insufficiently challenged over a period of time, which results in boredom and fatigue	The operator has limited awareness of what is going on and is not actively working to obtain SA knowledge
Situation awareness ***Low*** Workload ***Low***	Vigilance: Operator is required to continuously monitor a process but does not have to act, or has highly repetitive, homogeneous stimuli	Depending on the task this can result in stress and boredom.
Situation awareness ***Low*** Workload ***High***	Overload: The volume of information and / or tasks is too great	Operator can only attend to a subset of required information
Situation awareness ***High*** Workload ***High***	Risk for cognitive lock-up: High workload increases tendency to execute tasks sequentially	When focusing on one task, the operator is reluctant to switch to another task, even if the second task has a higher priority
Situation awareness ***High*** Workload ***Low***	No problems: required information is easy to process	High situation awareness can be achieved under conditions of low workload

2.3.6 HUMAN INFORMATION PROCESSING

Several researchers have proposed approaches to understand human information processing. The most basic view on human information processing is a stage approach, representing information processing as information linearly passing through isolated stages, such as perception stage, memory retrieval stage, and decision stage [44] [45]. Stage approach is mainly applied in literature to study the number and duration of stages to guide the development of mathematical models of information processing. The number and duration of stages are studied by measuring brain activity. An advantage of this approach is that it allows to measure information processing objectively. From a human factors point of view, the stage approach is useful as is points towards information processing steps which have design implications. The perception stage, for example, might require different design solutions than the decision stage. Non-linear relations between information processing stages and different elements of memory, however, cannot be captured with a stage approach.

In contrast to a stage approach, several human-machine interaction studies follow an ecological approach, such as for the evaluation of interface design for nuclear process control [46] [47], and cockpit interface design [48]. The ecological approach originated in the field of ecological psychology; the study of human-environment relationships and human perception in rich environments [49]. Ecological psychology addresses perception as natural vision constrained by the environment. The interaction of the human with his environment and the influence of the environment on human perception are at the core of the ecological approach to visual perception [50]. The ecological approach to human information processing is characterized as a looping, or spiraling, of perception and action. Human actions influence the environment, which directs further visual exploration of the environment [51]. The ecological approach claims that human information processing cannot be studied without first studying the constraints in the environment [52]. Adopting an ecological approach to human information processing in the study of operators' SA puts the emphasis on studying the 'situation'.

Cognitive engineering provides a somewhat in-between approach to information processing [53]. The cognitive approach follows a stage approach by using the stages of perception, comprehension, and projection for SA assessment. It, however, also takes into consideration that rules and mental models stored in long-term memory help human information processing [39]. While the ecological approach puts the emphasis on the 'situation', the cognitive engineering approach puts more emphasis on the 'situation awareness'. The cognitive engineering approach to human information processing as such is most in line with the commonly used theories on SA and therefore most applicable in our study.

The cognitive approach distinguishes three levels of human information processing; skill-based, rule-based, and knowledge-based [39]:

Skill-based level:

Information is processed automatically, which results in actions that are hardly cognitively demanding.

Rule-based level:

Input information triggers routine solutions, which leads to efficient problem solving in terms of required cognitive capacities.

Knowledge-based level:

Input information is analyzed and solution(s) are planned, which can involve a heavy load on the limited capacity of working memory.

Rules and mental models required for rule-based and knowledge-based information processing are stored in long-term memory. Information retained from long-term memory directs both perception and interpretation. Based on the interpretation of information, operators decide upon actions to take. Operators, however, do not necessarily use perceived information immediately. Instead, information can be temporarily stored in working memory and retained from there when needed [54].

To understand the role of human information processing for SA assessment, we implemented the cognitive engineering approach in our model of SA assessment. The resultant model of information processing for SA assessment is presented in Figure 2.5. This model shows that operators' SA can be improved by supporting (i) operators' perceptual capabilities, (ii) cognitive processing for information interpretation, (iii) the development of suitable schemata or prototypical situations in long-term memory store, and (iv) effective use of working memory.

2.4 Designing complex information systems to support operators' situation awareness

System factors influencing SA are especially relevant when operators use complex information systems in remote control environments. In these cases, operators rely on system user interfaces which present large amounts of related information sets. Designing complex information systems to support operators' SA requires a structured approach to handle both human factor aspects as well as complex information handling.

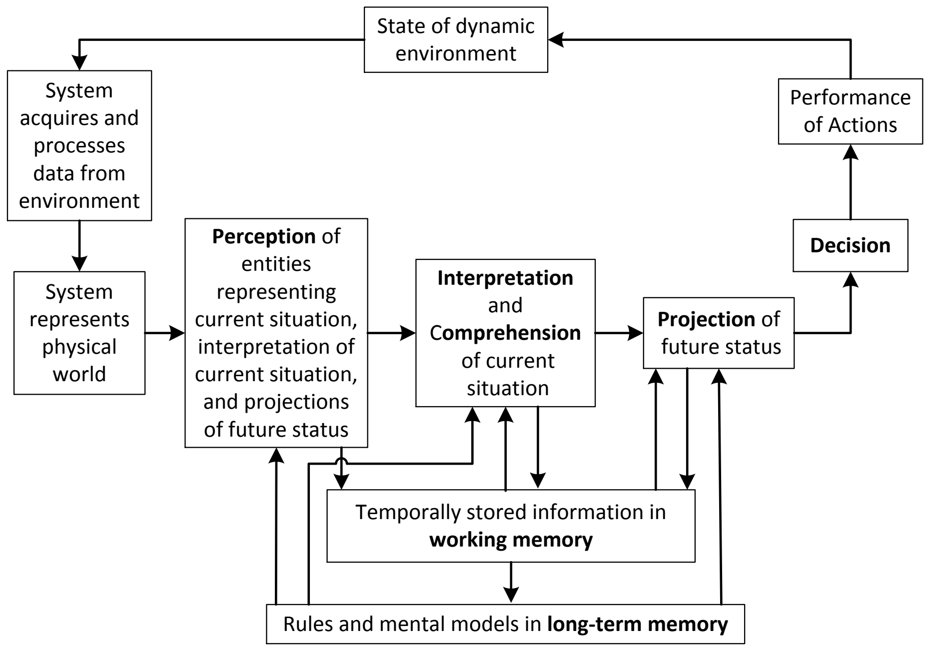

Figure 2.5 Model of human information-processing for SA assessment

2.4.1 USER-CENTERED DESIGN

UCD is one of the most influential design approaches in the field of human-computer interactions [55]. This approach aims to improve product usability by applying structured methods for acquiring user input in iterative cycles of contextual research, specification of user requirements, design activities, and user testing [56] [57] [58] [59]. Users' preferences, abilities, task demands, and resultant work activities are the focus points of UCD, which aims to minimize human errors in using products [59] [60] [61]. Many different approaches are commonly applied for UCD. For example, Wei and Salvendy reviewed 41 CTA methods for job or task design and analysis [62]. Salmon et al. evaluated 17 existing SA measurement techniques [22]. Paz and Pow-Sang identified 10 usability evaluation techniques in software development [63]. Many UCD techniques are used for different purposes. Interviewing, for example, is used for CTA, SA measurement, and usability evaluation [22] [62] [63]. Some researchers propose unstructured interviews, while many others provide protocols for structured or semi-structured interviews. Common UCD methods to capture the context of system use are observational research, interviewing, focus group sessions, and task analysis. UCD approaches to get users' input for defining user requirements are scenario or simulation techniques, evaluation of product use, evaluation of accidents, and focus group sessions. To capture users' input in design activities, prototyping and simulation are commonly used. These tools are also applicable for user testing. A challenge in this research was to identify which combination of UCD methods were most appropriate for the individual steps of the iterative design cycles and to complement existing approaches wherever it was needed.

2.4.2 INFORMATION ENGINEERING OF COMPLEX SYSTEMS

Navarre et al. [64] show that formal description techniques can be used to gain understanding of human-system interactions. They argue that without formal modeling, UCD of complex systems is likely to result in low quality software. To support iterative design of complex interactive systems, they propose a modeling framework which captures previous failures by combining task and system models with information from human error analysis, incident and accident investigation analysis, and barrier analysis. Their framework shows that graph representations support modeling of the connections of operators' tasks with the system, and that formal modeling is useful for representation of information flows in the task models. It shows that formal modeling can support designers in their analysis and concept development. The presented approach, however, relies on human error analysis and incident and accident investigations. Such analyses cannot be carried out in our practical case. Errors made by N-ONM operators do not commonly result in incidents. While we adopt the view that the design of complex systems requires both UCD and formal modeling, we require another formal-modeling approach than the approach presented by Navarre et al.

IE is a set of structured, data-oriented analysis and design techniques that support the design of complex information systems [65]. It can be used to design coherent and consistent information visualization by using mathematical logic to model relations between pieces of information, such as the principles of set theory and graph theory. Set theory provides a language of mathematical logic, which can be used to specify logic relations between information elements through mathematical equations [66]. It allowed us to specify information sets, map information sets to parts of the system, and describe mathematically how information should be handled by the system [67] [68]. Describing information handling rules in mathematical equations helps to safeguard system logics and consistency.

Relations between information elements can be visualized using graphs. The formalism of graph theory allows the representation of information entities as vertices and relations between information elements as edges between vertices. Subsequent edges connecting multiple vertices form a path, which can capture logical relations between multiple information entities [69]. Graph theory has many applications in IE, such as representing data structures and network design [70]. A special form of labelled directed graphs is a semantic network. A semantic network captures semantic relationships between information elements by applying directed and labelled edges in a graph. Edges can be labelled by annotations and using mathematical expressions, which can specify, among other things, the nature of information elements, different manifestations of an information elements, and conditions related to the use of information elements in the system [71]. Semantic networks are used to structure and represent knowledge; they are reasoning structures which enable to impart knowledge to intelligent systems [72]. Semantic networks can capture different levels of relationships between elements in a single graph, such as linguistic, conceptual, epistemological, logical, and implementation relationships [72]. This makes them suitable to support systems to reason about the knowledge [73]. Semantic networks are especially relevant when aiming to communicate complicated knowledge to systems, such as context-dependent or adaptive relations.

While IE is commonly applied for the design of complex information systems, it is not commonly linked to SA. Only two papers are found when searching for IE and SA at scopus.com, the largest abstract and citation database of peer-reviewed literature [2]. These papers propose to use model-based programming environments when designing to support operators' SA [74] [75]. Indeed, model-based development (MBD) is a commonly used IE approach to design and validate complex systems [76]. This approach provides modeling methods and tools to develop diagrams and mathematical equations to specify systems. It supports to model the interaction of physical systems with software by modeling component behaviors in diagrams and by specifying relationships between the components of the system [77]. The resultant models can be converted automatically into code and test cases, which allows testing systems before actual implementation [78]. Testing systems before actual implementation can help to gain understanding of human-system interactions, especially in cases of hardware-in-the-loop and human-in-the-loop testing. MBD of systems allows to design systems independent of input and output devices, which makes it suitable for defining context-dependent applications and cyber-physical systems [79] [80]. Since little studies report on using MBD when designing to support SA, it remains unclear which MDB methods and tools are most appropriate in our case.

2.4.3 DESIGNING EFFECTIVE AUTOMATION

Parasuraman et al. distinguished types and levels of automation that support to evaluate which system functions can most likely be successfully automated [81]. They proposed that automation can be targeted at (i) information acquisition, (ii) information analysis, (iii) decision and action selection, and (iv) action implementation. The degree to which these tasks are automated is referred to as levels of automation. Their model consists of 10 levels of automation; from no assistance at all (i.e. level 1) to a system which acts autonomously (i.e. level 10) [81].

Automation can reduce operators' workload by removing manual tasks and can be used to enhance operators' SA [27] [28] [82] [83]. The intricate relations between different human factor constructs, such as SA and workload, and large individual differences in operator's experience and innate abilities, however, make it difficult to predict the effect of automation on operator's performance [42] [84]. Automation can be ineffective for three different reasons: (i) operators' overreliance on imperfect automation, (ii) neglect of operators or underutilization of automation, and (iii) negative consequences of automation for workload, SA, and task performance [84]. These reasons are also interrelated.

Onnasch et al. showed that information acquisition and information analysis can be automated more safely on a high level, than decision and action selection, and action implementation [85]. The data presented by them suggest that support of SA assessment by automation is more likely to have a positive effect on operators' SA and performance, while high levels of automation of action selection and execution is more likely to reduce operators' SA. A lack of operators' SA due to automation, or human-out-of-the-loop problems, is especially problematic in cases in which automation fails or is otherwise unreliable [85].

2.4.4 VISUALIZATION OF LARGE AMOUNTS OF INFORMATION

An important system factor influencing SA is how information is presented to the users. Effective information visualization provides operators with relevant information insights, while poorly designed information visualization hides this insight, and can even misinform operators resulting in incorrect interpretations [86]. Effective visualization of information supports operators' perceptual capabilities to extract information, and can facilitate operators' cognitive processing [87]. Perception of information depends on how information is represented. Humans automatically search for stimuli which differ from a group of stimuli [88]. This so-called pre-attentive processing, for example, make that human unintentionally look at a large red rectangle in the middle of a picture which mainly consists of small black circles at a white background, see Figure 2.6. Different attributes of information presentation, namely color, motion, orientation, and size, direct operators' attention [89]. To support human information processing, the attributes applied to an information item should be in line with the importance of that information for the operator [90] [91].

Information visualization to support operators' cognitive information processing is most effective if it is predictable and coherent. This requires consistency of information display in terms of, for example, terminology, arrangements, and color use within and between information windows and

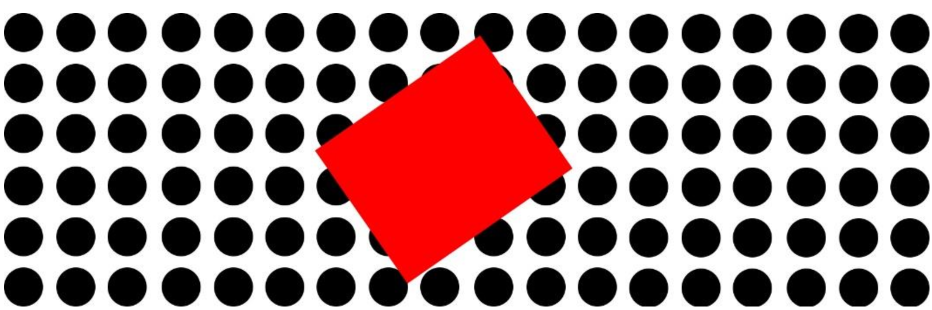

Figure 2.6 Pre-attentive processing makes that human unintentionally look at the red rectangle in this picture.

systems [90] [91] [92]. In the case of visualization of large amounts of information, it is required to (i) transform and cluster raw data into well-organized data sets, (ii) map the data into visual representation, and to (iii) display the visual representation to the users [86]. Information visualization is the creation and presentation of a mental model of the information and as such represents both values and relations between information entities [93]. In line with the ecological approach to human information processing, many researchers applied Ecological Interface Design for this purpose (For example [46] [47] [48] [49] [95] [96]). EID is a theoretical framework which is used to design user interfaces of complex systems [97]. EID aims to improve operators' SA by designing system user interfaces that represent the operators' work environment. This representation typically includes both the physical and functional aspects of the system to be controlled. This makes the EID framework especially relevant in cases where operators control complex physical systems, such as industrial systems, nuclear power plants, and airplane cockpits.

Many different representation techniques can be used to visualize information attributes, such as data values, patterns, and relations. Examples of representation techniques are tables, plots, (e.g. scatterplots, star plots), diagrams, maps (e.g. geographic maps, cluster maps), and iconic representations [98]. Which type of information visualization is most effective is not only related to data characteristics, but also to operators' goals and tasks. Information visualization which was successful in one field is not necessarily successful in another filed. The design of information visualization therefore should be concurrently addressed form both an IE and UCD point of view.

2.5 Discussion and reflections

The definition of SA proposed by Endsley, with a distinction in levels of SA (i.e. perception, comprehension and projection), is meaningful when aiming to understand how to support operators' SA. Operators need support to be able to (i) perceive relevant information, (ii) comprehend the situation, and (iii) forecast (near) future situations. When measuring SA, it is proposed to include queries about all three levels of SA. With current descriptions of the levels of SA it, however, is unclear where to draw the line between Level 1 SA and Level

2 SA. To our understanding, vessel names are part of Level 1 SA. But operator' goals seldom require operators to recall unrelated facts. It, for example, is not meaningful to recall vessel names without context. SA queries about vessel names, for example, will ask about names of vessels which are involved in an incident. To our understanding, this is about relations between information elements and thus part of Level 2 SA. When following this distinction between Level 1 SA and Level 2 SA, than Level 1 SA has little meaning to an operator. Consequently, it does not seem meaningful to include queries about Level 1 SA. In examples of queries, such as for air traffic control, it is not shown which query is related to which Level of SA [20]. All the example queries seem to include some relation between data. As we are unable to make a clear distinction between the levels of SA, we will not aim to classify information elements and SA indicators for measuring SA, such as SAGAT queries, in terms of level of SA.

Operators who successfully manage nautical operational networks understand the current and prospective meaning and relationships of large amounts of information about their dynamic environment. This includes relatively static knowledge of the area and waterways and rather dynamic data and knowledge of locks, bridges, waterworks, vessels, and weather conditions. For example they know, among other things, the cargo on board of a vessel, the direction of the wind, the type of companies located on the shore side of the waterway, and the potential hazardous relationship between these separate elements when determining which vessels can safely pass a fire at a company on shore. When an operator decides to close a waterway he must be aware of the locations of vessels on the waterway and if there is available anchorage ground for each type of vessel that is required to wait until the waterway has been reopened. Availability of anchorage ground is dependent on the size of the vessel, the type of cargo on board, and also the dynamic environmental conditions such as the water levels at the relevant period of time. The relevant period of time commonly comprises several hours or days.

A wide body of literature addresses the different knowledge areas related to designing complex information systems to support operators' SA. The literature review presented in this chapter shows that relevant knowledge areas are the system design, the process of information processing, and the context of tasks influence operators' SA, workload, and task performance.

Towards a holistic understanding of SA, all aspects as presented in our reasoning model, Figure 2.2, should be taken into account. This requires a structured approach to address the relations between the different knowledge areas. Although existing models do not provide a holistic view on SA, such a structured approach can be derived from existing theories. The following sub-section will derive an analysis scheme to holistically study required SA in cases when operators work with complex information systems. This analysis scheme will be applied in research cycle 2, where we aim to identify deficiencies of current SA support. Verification and validation of the analysis scheme will be addressed in that research cycle as well.

The area of UCD is closely related to human factors research. UCD approaches, such as observation, task analysis, and simulation are used both to support system design as to study human factors fundamentals such as SA, workload, and task performance. The large amount of UCD methods, however, makes it difficult to decide upon which methods to use. Besides, UCD lacks a structured approach to handle large amounts of information, which is typical for the design of complex information systems. IE does support designers in handling large amounts of information, but this field is not commonly linked with SA. Combined use of UCD and IE seems logical, but limited attention has been paid to how this can be done. Existing attempts to combine IE with UCD primarily focus on methods to include knowledge of human failure in IE models. This approach is not suitable when designing complex information systems for N-ONM. There is a need to consider how IE and UCD can complement each other when addressing complex systems for N-ONM. Both fields, however, comprise a wide range of design techniques. The main challenge in this research study was to select a proper and efficient combination of UCD and IE methods. This will be exemplified in research cycle 3, where we address potential user interface concepts to overcome deficiencies of current SA support.

2.5.1 DERIVING AN ANALYSIS SCHEME TO STUDY REQUIRED SITUATION AWARENESS

Smith and Hancock in 1995 already proposed that operators' goals, tasks, and information needs are relevant factors when studying SA [34]. Their definition of SA is similar to what in our theory is called the required SA. These factors alone, however, do not sufficiently define the influence of context on required SA. Current methods to define required SA, as discussed in sub-sections 2.3.3 and 2.3.4, address these different factors in separation from each other. They do not distinguish required SA from information needs, and no structured approach towards a more holistic understanding of SA is available.

Besides information needs, it is the man-machine interactions (MMIs), the interaction between goals, tasks, individual factors, and system factors, which influences required SA. This is in line with suggestions of other authors. Stanton et al. proposed to study the knowledge which is available within the technical systems, the knowledge which is required by the operator and the way in which they interact [99] [100]. However, they refer to both the information contained by the technical systems and the information of the human operators as SA. This creates unnecessary confusion. This thesis does not refer to knowledge within the system as SA. We nevertheless agree that it is important to understand the distribution of information between systems and operators when studying SA. As Mogford et al. pointed out, a distinction must be made between the operator's required SA knowledge and the display-based information [7]. Required SA knowledge is information which must be remembered and updated. Display-based information can be searched for when needed and forgotten [7]. Patrick and Morgan suggest that the cost of accessing information from an interface influences the likelihood of choosing either display-based or memory-based information processing strategies [31].

Combining the insights from Mogford et al., Patrick and Morgan, and Stanton et al., we propose that allocation of information and the resulting MMIs influence the SA assessment process and resulting memorized knowledge, as well as the operator's required SA. One can distinguish three types of allocation of information: (i) Information used by the system, but not relevant to the operator. (ii) Information presented by the system, which is relevant to the operator to be able to search for, but not necessary to memorize. Therefore this information is not part of the operator's required SA. And (iii) information derived from the system which is part of an operator's required SA. The decision to determine which information is part of operators' required SA is effected by the interaction between the individual operator, his goals and tasks, and the available systems. This is illustrated by the following example:

> *Imagine two operators, working with different man-machine interfaces. In case of a breakdown of a lock, they on request need to inform others about the queue time of another lock. Thus skippers can decide whether it is wise to take the alternative route. Imagine an information system, which displays the characteristics of all locks and waterways and a list of detailed information about all ships and the coordinates of their position on the waterway. With such a system, all data required to determine the queue time of a lock is available. It, however, is mentally demanding for an operator to decide upon the queue time of a lock. The operator needs to search for relevant pieces of information and understand their meaning and relations to predict the time it takes to transfer all waiting ships. It will take too long to recalculate the relevant queue time each time when someone requests this information. In order to be able to respond in a timely matter, information about the related ships, the lock, and queue time are part of his required SA. For an operator using a system which automatically displays the queue time of locks while hiding irrelevant data, accessing this information is not mentally demanding and takes a short time. Due to the moderate effort it takes to access this information, he most likely will process information differently. Detailed pieces of information which are only required to calculate the queue time do not have to be known. Therefore, they are less likely to be part of the operator's SA. This however does not mean that this operator has a lack of SA. The difference in man-machine interface influenced the required situation awareness knowledge.*

As illustrated by this example, understanding criteria for proper SA requires viable insight of the interaction between the operators and their task environment. In nautical traffic management and analogue contexts the goals of the operators are related to a remotely controlled task environment. These goals and tasks define the information necessary to successfully perform the tasks at hand and direct the man-machine interactions used to perform these actions. Different system designs can alter distribution of information between an N-ONM operator and the systems which he uses. System design influences whether operators are more likely to use display-based or memory-based information processing and thus influences operators' SA assessment [7] [31] [99] [100].

Besides system factors, individual factors also influence the decisions about which information is required. Processing of the required information for comprehension and projection to obtain and maintain SA takes place in the working memory [15]. Long-term memory can incorporate standalone facts such as object names, and also mental models, schema and scripts developed over time and from experience. Long-term memory plays a significant role in improving an operator's SA [15]. Pointers from working memory to long-term memory can activate mental models or schema supporting comprehension and projection, and filling in missing information. The working memory provides the current situation values of the activated mental model or schema [32]. An operator who can successfully use a mental model to fill information gaps can be sufficiently supported with an information system which provides partial information. An operator unable to create or utilize a mental model to compensate for missing information considers the information gap as a deficiency of the current support system.

An employer commonly demands for a minimum level of operator competence. Required SA therefore depends on the implemented demands for operators' competence. The pieces of information, which are the most essential for an operator's SA, are influenced by the interaction between goals, tasks, system factors, and individual factors. In conclusion, we propose a distinction between information needs and required SA, which is defined as follows:

> ***Information needs*** *is all the information which is necessary to reach operator's goals successfully.*
>
> ***Required situation awareness*** *is the essential information about the dynamic environment, which operators need to have mentally available during task performance, where necessity and relevancy depend on information needs and the interaction between goals, tasks, individual factors, and system factors.*

Information needs are related to operators' task and goals, and can be captured in a static overview. Required SA on the other hand is related to the dynamic environment and man-machine interactions. As a result, required SA is context dependent. In line with this definition we propose an analysis scheme to support a systematic and structured study of required SA, see Figure 2.7. This scheme places the different aspects in logical relationships that are needed to define required SA in case of complex MMIs. It is derived from existing theories by critical synthesis. Existing partial theories of SA have been combined and transformed to represent the relations between the different sub-theories. The different sub-theories used are all built upon Endsley's theory [13]. They add new insights to specific aspects of Ensley's theory, without adding internal inconsistency. The used partial theories are reasonably and comprehensively tested.

The different steps presented in the analysis schemes are as follows:

1. In line with Endsley's theory [13] and the insights of Smith and Hancock [34], the starting points of processing the analysis scheme are the operators' goals and tasks. Cognitive task analysis (CTA) methods are commonly used UCD methods to identify and specify operators' goals and

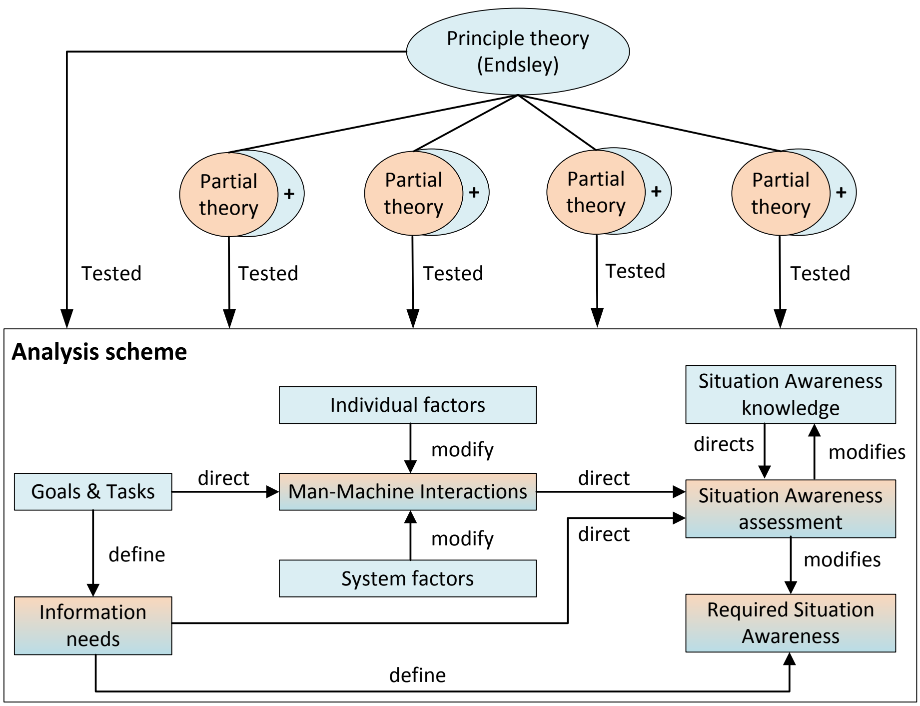

Figure 2.7 The process of combining tested existing theories in an analysis scheme to study required situation awareness in a holistic matter

tasks. Applied Cognitive Task Analysis (ACTA) is a commonly used CTA method to define operators' tasks, while Goal Directed Task Analysis (GDTA) is commonly used to define operators' goals [36] [101] [102].

2. The goals and tasks define the information necessary to successfully perform the tasks at hand. This is in line with how Endsley and Jones use GDTA to define SA requirements [36]. We, however, refer to this as 'information needs', instead of 'SA requirements'.
3. A novelty of this scheme is that it concurrently considers the three influential factors of SA, as addressed in the literature discussed in sub-section 2.3.3, as factors influencing man-machine interactions that direct SA assessment. Since this is a novel approach to the study of SA, existing UCD methods do not sufficiently support this step of our analysis scheme.
4. In line with the reasoning of Mogford et al., Patrick and Morgan, and Stanton et al., the analysis scheme points out that the MMIs and information needs together result in an allocation of information between operator and system [7] [31] [99] [100]. This directs the information processing strategies used for SA assessment.
5. A new insight presented by this analysis scheme is that the information processing strategies, such as memory-based or display-based strategies, used for assessment will modify the required SA. Information used by the system, not displayed to the operator, will not be part of the operators' SA. Neither will information belonging to display-based information processing strategies. Thus, the design of MMI can significantly reduce the operators' required SA. At first sight, this seems similar to the concept of distributed situation awareness (DSA). DSA aims to provide a methodology for capturing the distribution of information between systems and human operators [100]. It, however, only provides a method to capture how knowledge is used between human operators and systems at a given situation. It cannot be used to define required SA in line with this analysis scheme, as it does not capture how necessity and relevancy of information depends on the interaction between goals, tasks, individual factors, and system factors. As this approach to addressing the required SA is novel, no UCD methods that are in line with this analysis scheme, are currently available for this purpose.
6. Consistent with Adams et al. the analysis scheme presents the cyclical relation between SA knowledge and SA assessment [30]. As SA knowledge

influences operator's expectations, the present SA knowledge influences SA assessment to update the SA knowledge. Both explicit and tacit knowledge about the dynamic environment are part of SA knowledge of the operators, and both will influence the SA assessment. In this analysis scheme, operators are considered to have a lack of SA when their explicit and tacit knowledge together do not cover all aspects of the context specific required SA.

The analysis scheme points out which aspects need to be part of UCD contextual research activities. Several, but not all aspects of the analysis scheme can be studied using existing UCD methods, namely ACTA and GDTA. In the next chapter, Chapter 3, we present which steps of ACTA and GDTA relate to which steps of the analysis scheme and which extra activities are required. The output of the contextual research activities, also presented in Chapter 3, is necessary input for the next steps of UCD; specification of user requirements, design activities, and user testing. In Chapter 4 we present how UCD methods are complemented with IE methods in designing complex systems for N-ONM.

2.6 References

This chapter is based on:

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[c] Van Doorn, E.C., Horváth, I. and Rusák, Z. (2017) 'Information engineering for developing and testing coherent, integrated and context dependent user interfaces' Cognition, Technology & Work, Vol. 19 No. 2 – 3, pp. 375 – 397.

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CHAPTER 3

Research Cycle 2

EXPLORING DEFICIENCIES IN SUPPORTING SITUATION AWARENESS

In the previous chapter we discussed the state of the art of situation awareness (SA) research. We identified limitations of applying current SA theories in the field of nautical operational traffic management (N-ONM). To overcome these limitations, we presented a definition to distinguish required SA from information needs. We derived an analysis scheme which allows a holistic study of SA. In this chapter, the analysis scheme is operationalized. This chapter has a dual objective. In our first research cycle (RC), we aim to define required SA in complex information systems context. Operationalization of the analysis scheme is required to justify and validate its logical properness. In our second RC, we aim to identify deficiencies of current support of N-ONM. To this end, current common methods to identify deficiencies related to the support of SA are discussed in section 3.1. Since these methods cannot be applied in our case study, section 3.2 presents how operationalization of the analysis scheme is also used as input to identify deficiencies of SA support. Section 3.3 presents the steps of data processing to identify deficiencies of current support systems. Finally, the discussion and conclusion in section 3.4 addresses the validity of the analysis scheme and data processing approach.

3.1 Common methods to identify deficiencies

A common existing approach to finding deficiencies of support of SA is the analysis of accident reports [1] [2] [3]. In N-ONM context, improper operators' SA can result in slow incident handling, distribution of false information, and can cause delays in traffic flows. It, however, seldom results in accidents and there are no N-ONM accident reports available to study sources of SA errors. Another method proposed to study SA errors is to assess operators' SA in simulated scenarios [4]. This method is commonly used to evaluate systems designed to support SA assessment [5] [6] [7]. The use of simulated scenarios to assess deficiencies of supporting SA requires a sufficiently realistic simulator. However, at the start of this research cycle, there was no N-ONM simulator available. Building such a simulator is costly and time consuming, and requires a deep insight into the simulated tasks and environment. Using simulated scenarios to identify deficiencies of support of SA in N-ONM context therefore was not a realistic option in the short-term. Some researchers have proposed to use observational research to assess SA in the context of a real life operation. Generally, a combination of operators' self-rating and subject-matter experts' (SMEs) observer rating is used. Several researchers, however, also indicate that the extent to which operators and observers can accurately rate SA is questionable [8] [9]. Therefore, it is uncertain to what extent we are able to identify deficiencies of supporting SA for N-ONM tasks if we solely use observational research methods.

3.2 Applying the analysis scheme to identify deficiencies

Cognitive task analysis (CTA) is a collection of methods which aim to support researchers in identifying and understanding cognitive activities which are needed to perform a task proficiently [10]. These methods provided researchers with a large amount of data about the studied task environment. We consider this data as a potential source to study deficiencies of supporting SA, but as far as we know, no research has reported a systematic approach to use CTA data for this purpose. In this research, we explore to what extent a structured analysis of CTA data can complement the analysis of observational research data in identifying deficiencies.

Current CTA techniques address parts of the analysis scheme which we presented in the previous chapter. Endsley and Jones [11] propose goal-directed task analysis (GDTA) as a CTA technique to define required SA. GDTA has been successfully conducted for several studies in the field of aviation [12]. GDTA proposes to conduct an analysis of documentation, interviews with experienced operators, and confirmative observation of operators fulfilling their duties. Similar to this method is the well documented applied cognitive task analysis (ACTA) approach proposed by Militello et al. [13] and Militello and Hutton [14]. The main difference between these methods is that GDTA focuses on goals, whereas ACTA focusses on tasks. ACTA uses three interview tools [13] [14]:

- ***Task diagram:***
  A technique aimed to obtain an overview of tasks and to gain insight into those tasks which require expertise.
- ***Knowledge audit:***
  A technique used to capture aspects of expertise. A knowledge audit involves questions regarding the cues and strategies operators use, and questions about experienced difficulties.
- ***Simulation interviews:***
  A technique by which operators are asked what they would do in situations that are specified by the interviewer.

In our research set-up we used GDTA and ACTA to address the different steps presented in our analysis scheme where possible. When these methods were not suitable to address an aspect of the analysis scheme, we proposed a different method instead. A total of 22 N-ONM operators and eight SMEs were involved in this research. The operators voluntarily participated in the CTA sessions. For discussions, the group was divided in two groups, one of 10 and one of 12 operators. The operators performed the ratings individually. Simulation interviews were carried out in pairs.

While operators and SMEs experienced difficulty in directly describing their required SA, all operators were able to provide valuable response to the different steps as described in the following subparagraphs. The list of information needs per tasks helped operators to evaluate strategies and cues. Through simulation interviews and with this list, they were able to indicate which information is part of required SA, and which information is relevant but not part of required SA. Once the SMEs and the operators reached an agreement on the goals & tasks overview, the operators were asked to carry out their tasks in line with the agreed goals and tasks overview over a three month evaluation period. Observations took place during this period.

3.2.1 RESEARCH STEPS TOWARDS IDENTIFYING THE GOALS AND TASKS OF N-ONM

The first step in the analysis scheme is to identify operators' goals and tasks. GDTA is commonly used to define operator' goals while ACTA aims to identify tasks. These two methods use different research techniques. To capture both goals and tasks, we combined GDTA and ACTA. To be able to link insights in goals and tasks to man-machine interactions (MMI), we added extra activities; discussing the level of information processing, error probability, and mental workload of cognitive tasks. This resulted in the following research steps:

Step 1. In line with GDTA, we analyzed documentation and used unstructured interviews with SMEs, and three semi-structured group sessions with SMEs to define goals, tasks, sub-tasks, and activities. Additionally, we asked the SMEs to define the level of information processing, as defined by Rasmussen, for each activity [15].

Step 2. Prior to an ACTA Task Diagram session, N-ONM operators validated the generated overview

Step 3. In line with ACTA, N-ONM operators were involved in a 'Task Diagram' session. The ACTA approach proposes to ask "*Which subtasks require the most expertise*?" [13]. Prior to this question we asked operators to individually rank the error probability and mental workload of all the identified cognitive tasks.

Step 4. In line with GDTA, the generated overview was validated through confirmative observation of operators fulfilling their duties.

In the order of priority, the goals of N-ONM operators are to contribute to achieving: (i) safe water levels, (ii) sufficient clean water, (iii) safe traffic situations, (iv) efficient traffic flows, and (v) reliable and useful information to skippers, colleagues and emergency services. However, N-ONM operators do not have an active role in all of these goals. Water levels and water quality provide the limiting factors within which they need to operate, but they do not actively manage those. The other three goals are interconnected and require execution of the same tasks from the N-ONM operators. Table 3.1 gives an overview of all the identified tasks and subtasks for operational network management. The list of activities per sub-task and the defined level of information processing are included in Appendix I. The results of operators ranking the error probability and mental workload of the cognitive tasks are given in Appendix II.

Table 3.1 Tasks and subtasks belonging to N-ONM

Tasks	Sub-tasks
Assess traffic conditions	Locate / identify shipping
	Follow shipping
	Observe network
	Register information
Inform stakeholders (skippers, emergency services, colleagues)	Provide traffic information
	Provide information in case of restrictions
Manage incidents	Take active actions for incident management
Plan traffic measure (planned restrictions)	Determine impact (planned restrictions)
Plan traffic measures (unplanned restrictions)	Determine impact (unplanned restrictions)
	Prepare traffic measures (unplanned restrictions)
Set / release traffic measure (planned and unplanned restrictions)	Take actions to remedy limitations and to effect traffic measures
	Set traffic measures
	Lift traffic measures
	Register information

3.2.2 RESEARCH STEPS TOWARDS DEFINING N-ONM INFORMATION NEEDS

We defined information needs per activity, similar as GDTA proposes to define SA requirements. The Goals & Task overview was used as input.

Step 1. We reviewed operator’s handbooks
Step 2. We used unstructured SME interviews
Step 3. The involved N-ONM operators validated the generated overview

The information needs of all activities taken together include 91 items, which were clustered into (i) waterway, (ii) shore, (iii) waterway signs and information elements, (iv) object, such as bridges / sluices, (v) hydrology and meteorology, (vi) vessels, (vii) cameras, (viii) restrictions, (ix) measures, and (x) communication. Discussions about the information needs revealed that they can be divided into static information which operators know by hearth, and static and dynamic information which needs to be accessed during task performance. Operators agreed that successful task performance requires them to know by heart a significant amount of information. However, even highly experienced operators are not considered to be capable to memorize all the relevant information and relations. This outcome confirms the distinction between information needs and required SA as proposed in the analysis scheme. The total overview of information needs which resulted from these steps is given in Appendix III.

3.2.3 RESEARCH STEPS TOWARDS UNDERSTANDING HOW MAN-MACHINE INTERACTIONS INFLUENCE SITUATION AWARENESS ASSESSMENT

In line with the analysis scheme, we used the generated Goals & Tasks overview as input for discussing MMI. The generated information needs overview was used as input during simulation interviews, in which we discussed how MMI influence SA assessment.

Step 1. ACTA's Knowledge audit interviews with SMEs were used to gain insight into individual factors that influence MMI, such as expertise, cues and strategies used, and experienced difficulties.

Step 2. ACTA proposes 'Equipment' as an optional probe during Knowledge audits [14]. As we explicitly aim at addressing all the aspects of the analysis scheme, we consider this probe essential to address system factors which influence MMI. We triggered discussion about equipment through the following questions:

- Which systems do you use and how to form a mental picture and to monitor the situation?
- What are the defects / limits of the systems used?

Step 3. We triggered discussion about MMI by adding the question:

- How do you deal with these defects / limits of the systems used?

Step 4. Although ACTA Simulation interviews were used to gain further knowledge about MMI, the main focus of these interviews was to gain insight into SA assessment. For simulation interviews, the ACTA proposes to ask one question about information assessment: *"What pieces of information led you to this situation assessment / action?"* [13]. To gain understanding of how MMI influences SA assessment, we additionally asked the following questions :

- What information do you request from others?
- What information do you search for in your information systems?
- What information do you use from your own situation awareness?
- Are there alternative ways in which you could assess this information?
- When is it, and when is it not, appropriate to use this alternative?

The interviews showed that current information systems used to support N-ONM tasks mainly provide support of Level 1 SA. The systems do not provide rapid access and understanding of information about current and anticipated traffic intensity or restrictions on the waterways. Estimated time of arrival of vessels is provided, but is not considered reliable. Hydrology and meteorology information includes prognosis information. SMEs and operators agree that current circumstances require experienced operators. They need to rely on extensive knowledge about the area of control, such as names and characteristics of waterways, sluices and bridges. The systems core functions are to support operators in their communication with skippers and emergency services by providing information about vessels, voyages, and environmental circumstances. The user interfaces of current systems do not provide rapid access and understand-ability of needed information.

3.2.4 RESEARCH STEPS TO DEFINE REQUIRED SITUATION AWARENESS

As the theories behind ACTA and GDTA do not distinguish required SA from information needs, extra actions are required to capture this distinction.

Step 1. While addressing the ACTA knowledge audit probe ' Big Picture', we not only asked "*If you were watching novices, how would you know that they don't have the big picture*?" [13]. We more explicitly discussed required SA by asking:

- What information should continuously be part of your mental picture of the situation?
- What information do you need to monitor?

Step 2. Additionally, operators were asked to consider current MMI while they individually rated the identified information needs on two aspects on a scale of 1 (not important) to 5 (very important):

- Importance of searching for this information during the task, although afterwards it can be forgotten.
- Importance of memorizing this information, to make it part of your situation awareness.

While current support systems mainly provide support of Level 1 SA, N-ONM tasks are mainly related to comprehended and projected knowledge about the current situation. N-ONM required SA includes comprehension of traffic conditions, i.e. Level 2 SA, such as understanding threats for safe traffic flows and affected vessels in case of restrictions, and projection of the impact of restrictions and traffic measures; Level 3 SA. Information elements which are considered most important to memorize for proper SA are shown in Figure 3.1. This figure shows boxplots of how these elements were rated by the operators.

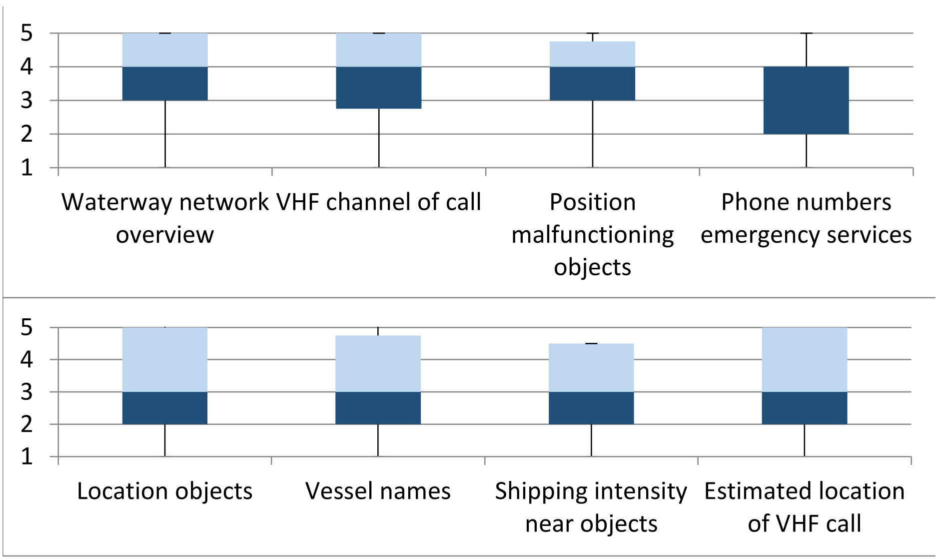

Figure 3.1 Ratings of importance to memorize information elements of those elements which were rated highest

The main information elements which operators need to access, but may forget afterwards are given in Figure 3.2. This figure shows boxplots of how these elements were rated by the operators. Figure 3.3 shows boxplots and standard deviation of the ratings for the four information needs which are considered of main importance to access, but are not considered as main importance to be included in required SA. It shows a large variation in ratings among operators. Discussion among operators revealed that variation is mainly caused by different levels of expertise. Highly experienced operators tend to have more information as part of required SA compared to less experienced operators. Information elements which are not considered of main importance to include in required SA are still ranked above 1 by several operators. In specific situations these elements can become important for operator's SA. As an example, information about companies near the

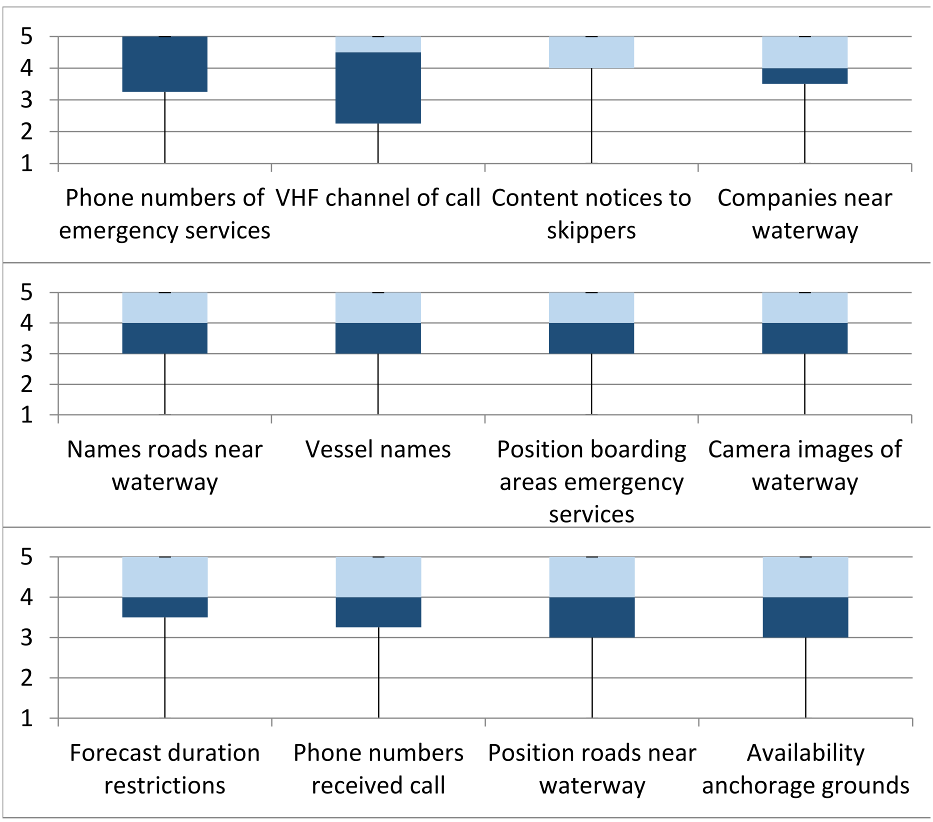

Figure 3.2 Ratings of importance to search for information elements of those elements which were rated highest

waterway commonly does not need to be part of operators' SA. However, in the case of a fire at a LPG terminal near the waterway, information about this specific company becomes part of required SA. Therefore, which information becomes part of the operator's required SA is operator and context dependent.

Much more information elements are rated as very important to being able to access that information then as very important to have mentally available. When looking at the scores for importance to access information, 44 elements are rated with a median of four or higher. In comparison, only four elements are rated with a median of four or higher on the aspect of importance to have these elements as part of operators' SA. Appendix III shows the median of rates for all information elements.

Combining the insights from all interviews, we developed a comprehensive description of required SA for N-ONM tasks. In this description, we highlighted the difference between the required situation awareness and the required information needs. All information from the list of information needs is relevant, but not all information is equally important. We presented this insight to 24 operators, who were not involved in the earlier described sessions, and three SMEs. They confirmed our view on the required situation awareness and the related information processing strategies used.

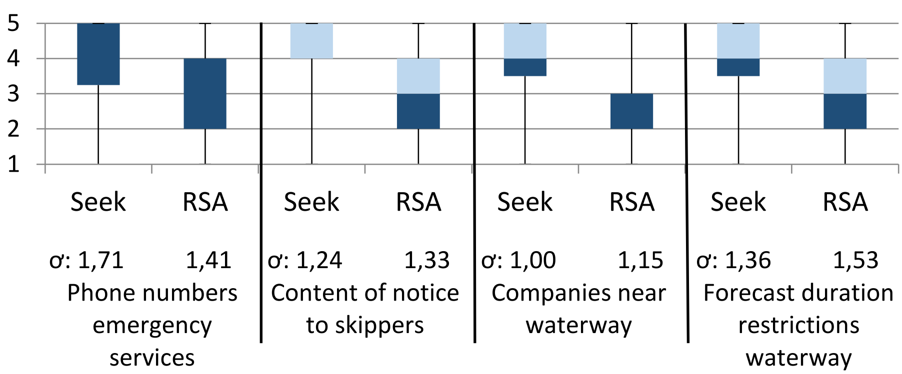

Figure 3.3 Ratings of information needs, where "Seek" represents the ratings for "Importance of searching for this information during the task, although afterwards it can be forgotten" and "RSA" represents ratings for "Importance of memorizing this information, to make it part of your situation awareness".

3.3 Information elicitation to identify deficiencies of current support systems

Large amounts of transcribed recordings of design related research methods can be analyzed semantically to develop a comprehensive set of relevant data [16]. We processed the CTA data and observational research data generated in the previous steps both syntactically and semantically so that deficiencies of support of SA can be identified accurately and objectively. The steps required for syntactic and semantic processing are presented in Figure 3.4 and clarified in the following subparagraphs.

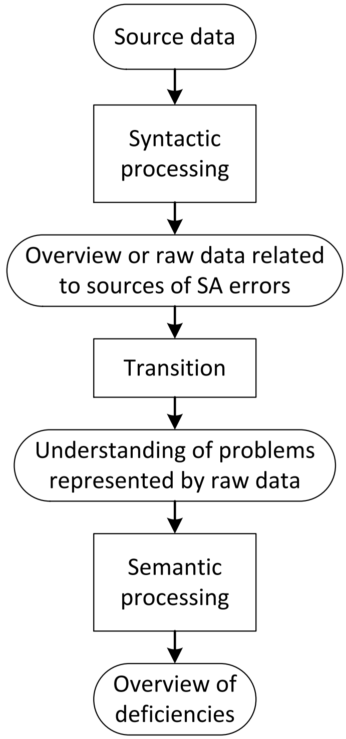

Figure 3.4 Overview of steps and products of syntactic-semantic processing

3.3.1 SOURCES OF DATA

The CTA data consisted of:

- Overview of N-ONM tasks, subtasks and activities
- Overview of required information elements per activity
- Ratings of mental demand for all cognitive activities
- Ratings of error probability for all cognitive activities
- Ratings of required availability for information elements
- Ratings of importance for RSA for information elements
- 87 minutes audio recordings on Goals & Tasks
- 32 minutes audio recordings on Information needs
- 104 minutes audio recordings of Knowledge audits
- 11 completed templates of Simulation interviews
- 83 minutes audio recordings of Simulation interviews

The audio recordings on Goals & Tasks contain discussion on the mental demand and error probability of the cognitive N-ONM tasks. The audio recordings on information needs contain discussions on the required availability of the different information elements and their importance for required SA. The reason for the relative short session is the high level of agreement among the participants. The audio recordings of knowledge audits contain discussions on operators' cues, strategies, and experienced difficulties. The simulation interview audio is a record of 11 presentations of operators' answers on what they would do in the generated simulated situations. Each presentation was followed by a group discussion. The overviews, ratings, and templates were discussed in the audio recordings. These discussions contained the information as listed on these forms as well as insights gained through discussion with colleague operators. Therefore, syntactic processing only incorporated the audio data. The information listed on the forms, however, was used to interpret the audio recordings during the syntax-semantics transition.

The observational research data consisted of results from a questionnaire, observer checklist, and observer notes. Operators were asked to fill in a questionnaire after the observed shift. This questionnaire was compiled of (i) open questions in order to provide a description of the observed tasks and task environment, (ii) rating questions to capture which information was part of the SA of the operator, (iii) rating questions as proposed by the SART [17], (iv) open questions asking operators to clarify why they rated SART aspects as they did, (v) open questions about opportunities identified by the operators to improve task performance, the current workplace, and used information systems, (vi) rating questions about experienced problems with current information systems, and (vii) ratings of the experienced physical discomfort.

An observer checklist was developed to aid the observers in a structured evaluation of operators' SA. The checklist consisted of observed behavior concerning (i) requested information, (ii) provided information, (iii) directing patrol vessels, (iv) the use of different information systems, (v) problems with searching for relevant information such as availability of information or communication difficulties, (vi) problems with interpreting and using information. In addition to a subjective judgement of SA, the notes of the observer included logs of all operator's actions, incoming information, and events. Besides, the observant made notes on the traffic situation such as traffic intensity, and on the operator's work attitude.

This research used data from six observations which covered 7 hours of task performance in total. The aim was to have representative observations, but also to increase the chances to identify deficiencies. The operator population in N-ONM context is dominated by experienced operators. To fulfill both objectives, we observed (i) four experienced operators, who have more than 10 years of experience in N-ONM tasks and are highly familiar with this specific area of control, (ii) an unexperienced operator with less than a year experience in N-ONM tasks, and (iii) a color blind and bespectacled operator with less than five years of experience in this specific area of control.

3.3.2 SYNTACTIC PROCESSING OF RESEARCH DATA

We applied three syntactic analysis steps to generate an overview of all the references to deficiencies in the data:

Step 1. Transcribe audio recordings and/or remove irrelevant text. Examples of irrelevant text are off-topic discussions prior to the interviews. Underline all text which is related to deficiencies of support of SA. This means to underline all text about shortcomings of, or problems with, aspects of the analysis scheme. This can be text related to (i) operators' goals and tasks, (ii) human factor constructs such as operators' innate abilities, workload, information processing, and task performance, (iii) system factors, (iv) man-machine interactions, (v) information needs, (vi) SA, required SA, and SA assessment.

Step 2. Process all underlined text. Arrange identical words (e.g. 'overload' and 'overload'), synonyms or similar expressions (e.g. 'disturb' and 'interruption'), and phrases which use different words to describe the same phenomenon (e.g. 'wrong vessel' and 'other skipper') in groups. Arrange dissimilar words and phrases in new groups.

Step 3. List the sources and frequency of occurrence for each of the groups generated in step 2.

The resultant overview of raw data related to sources of SA errors is given in Appendix IV.

Manual transcription of speech recordings takes approximately 10 times as long as the actual duration of recording [18]. Background noise and people that talk over each other increase the time needed for transcribing the recordings. These also increase the risk that errors are made. To prevent transcription errors, we intervened in cases of off-topic discussions and when multiple people talked at the same time. Operators used technical terms, abbreviations, and imprecise formulations. This may cause difficulties for a layman to interpret data for syntactic processing. Therefore, the discussion leader asked operators to explicitly clarify those expressions which might not be commonly known. Furthermore, we had expert knowledge in the studied context and thus were able to syntactically process the raw data.

3.3.3 SYNTAX-SEMANTICS TRANSITION

The results of syntactic processing feed into syntax-semantic transition. The data captured through CTA and observational research did not directly represent the deficiencies of supporting SA. SA is an abstract construct. Operators cannot directly observe how something hindered them in gaining SA, nor can they objectively determine that they had a lack of SA. Instead, they for instance experienced difficulties in task performance. Therefore, CTA or observational research data is mostly not directly related to SA. A syntax-semantics transition is required to relate the semantic groups to the object of study, namely deficiencies, and the SA construct. The transition process will not be reproducible if the construct of SA purely depends upon the researcher’s mind. To structure this transition, we therefore use the ‘analysis scheme to study SA in a holistic matter’ presented in the previous chapter. We proceeded as follows:

Step 4. Use context information to formulate the related problem per syntactic group. Context information can be information from the same data source, or information to which the data source refers.

Step 5. Relate the syntactic groups to the analysis scheme. Identify which influential factors (‘Goals & Task’, ‘Individual factors’, ‘System factors’, ‘Information needs’) play a role. Identify which aspects of SA (‘SA knowledge’, ‘SA assessment’, ‘Required SA) are affected.

The results from step 4 are included in Appendix IV. The results from step 5 are shown in Appendix V.

In discussions, mutual understanding among operators may result in the use of unfinished sentences and reference examples. When all the participating operators know what happened during a sever fire at a chemical company near Moerdijk, and remember what kind of influence this had on traffic management, then by mentioning Moerdijk, they, for instance, may refer to a situation with similar circumstances. The context information required to formulate the problem, and /or to relate the problem to the construct of SA, therefore might not be explicitly mentioned in the raw data. During CTA sessions, the discussion leader explicitly asked operators to clarify reference examples to minimize the need for interpretation based on background knowledge during data processing. Table 3.2 gives two examples of syntactic groups, their problem description, and their relation to the SA construct.

Table 3.2 Example of syntactic-semantic processing

Step 1 – 2. Syntactic group: *irrelevant questions; unimportant information; unnecessary input fields*	**Step 3. Sources:** Questionnaire (2); Observer notes (1)
Step 4. Problem: The used information system requires operators to enter information which is irrelevant for them. While busy filling in irrelevant input fields, they are not able to process other more relevant information to gain and maintain SA.	**Step 5. SA construct:** System factors. SA assessment.
Step 1 – 2. Syntactic group: *inserting information takes much time*	**Step 3. Sources:** Questionnaire (1)
Step 4. Problem: Entering information is time consuming, and this distracts them from SA assessment.	**Step 5. SA construct:** Goals & Task factors. SA assessment.
Step 6 – 7. Deficiency: System does not support efficient insertion of information, which hinders SA assessment	
8. Classification: Workflow	

3.3.4 SEMANTIC PROCESSING

Semantic processing is used to formulate deficiencies:

Step 6. Combine syntactic groups which address the same phenomenon with different indicators or from different perspectives. Table 3.2 presents an example of how two syntactic groups can be combined into a single deficiency.

Step 7. For each group, use the formulated problem(s) to define a deficiency, all on the same meaningful abstraction level. Combine problems of a lower abstraction level if they belong to the same problem on a higher abstraction level.

Deficiencies should emphasize the core of the problem. A deficiency formulated as “The system does not support SA assessment” is too imprecise, while “The long list of ships in the IVS’90 system requires a lot of scrolling” is too particular. A meaningful abstraction level is, for instance, “The current information presentation puts high demands on operators’ ability to keep overview of a large area of control”.

Deficiencies can be related to different factors which influence operators’ SA. Consequently, different types of deficiencies may require different measures.

Step 8. Use the defined influential aspects and affected aspects of SA from the syntax-semantics transition to classify the defined deficiencies.

We introduced a classification of the identified deficiencies to guide designers’ choices in directions for design solutions:

(i) Circumstances deficiencies; related to context specific conditions,
(ii) Informing deficiencies; related to the interaction between operators and information systems to access information,
(iii) Workflow deficiencies; related to (inefficiency in support of) work methods, processes, and activities,
(iv) Cooperation deficiencies; related to dependencies on others,
(v) Ability deficiencies; related to operator’s skills and capabilities.

A deficiency is classified in two categories if it relates to both. We developed this classification to support our N-ONM case study. In a different context of study, another classification might be more suitable.

The results of the semantic processing steps are given in Appendix IV and V. One-third of the deficiencies were classified as informing deficiencies. One-third of the deficiencies were related to circumstances. Other deficiencies were classified as related to workflow, cooperation, and abilities.

3.3.5 DEFICIENCIES OF SUPPORTING SA OF N-ONM OPERATORS

The results of the proposed information elicitation approach incorporate more than just a list of deficiencies of supporting SA. They provide a rich overview of background knowledge for each deficiency. When studying this overview, we identified that some of the identified deficiencies had a cause and effect relation. This can be illustrated by the following example.

> *Knowledge audit interview data indicated that operators experience a lack of SA as it is difficult to access all the relevant information with current information systems. Further inquiry in this deficiency showed that the main reason of the observation is that information needs to be searched in information systems which contain large amount of information. Although all this information is relevant to the operators at some point, it makes it difficult to distinguish which information is relevant now. The observational data showed that information sometimes is difficult to access because the system intended to provide this information is not fully functional or available. The knowledge audit interview data also indicated that in some cases, information is required sporadic and due to lack of experience with searching for this information, operators find it difficult to access this information. Goal & Task overview data indicated that current information presentation puts high demands on operator's ability to keep overview of a large area of control. Further research into this deficiency indicated that the large amount of information and the difficulty to access relevant information are important cause. Other mentioned causes are that some information is only available in operator's mind, that operators receive no direct feedback on own actions, and that the time component of information is not supported by the systems. These two last causes are also mentioned when studying the deficiency that N-ONM operators miss, forget or skip relevant actions. This deficiency was firstly identified through the study of Simulation interview data.*

As this example illustrates, the different deficiencies were indicated at different points in the data and in different contexts. A matrix was used to capture all the relations between deficiencies. Taking these relations into consideration, 23 of the 30 identified deficiencies were related to how the current system interfaces support human information processing. These deficiencies were clustered into four main groups:

D.1. Operators experience insufficient quality of information

D.2. Operators have difficulty to access information

D.3. The used information visualization techniques put a high demand on operators’ ability to maintain an overview of a large area of control
D.4. Operators do not execute all relevant actions

Table 3.3 shows the resultant cause and effect relations of each group of deficiencies.

Table 3.3 Cause and effect relations of deficiencies of supporting N-ONM (continues on next page)

Deficiency group	Related causes	Related effects
Insufficient quality of information in systems	Required information of others unreliable	N-ONM operators require the ability to improvise
	Some information is subject to change	N-ONM operators take wrong or no timely action
	Operators require large amount of information	
Difficulty to access information	Operators require large amount of information	Insufficient quality of information in systems
	Required systems not fully functional or available	Current information presentation puts high demands on operators’ ability to keep overview of a large area of control
	Some information is required sporadic	
Current information presentation puts high demands on operators’ ability to keep overview of a large area of control	Operators require large amount of information	N-ONM operators take wrong or no timely action
	Difficulty to access relevant information	
	Some information is only available in operator's mind	
	Operator receives no direct feedback on own actions	
	Time component of information not supported by systems	

Table 3.3 (Continuation from previous page) Cause and effect relations of deficiencies of supporting N-ONM

Deficiency group	Related causes	Related effects
Operators miss, forget or skip relevant actions	Operator receives no direct feedback on own actions	
	Time component of information not supported by systems	
	Mental workload exceeds operator's mental capacity	
	N-ONM operators are exposed to stressful situations	
	N-ONM requires to pursue multiple tasks simultaneously	
	N-ONM operators do not follow a uniform working method	
	N-ONM goals do not all receive the required amount of operator's attention	
	N-ONM actions have far-reaching consequences	
	Criticism about work of civil servants limits freedom of actions	
	System does not support efficient insertion of information	

3.4 Justification and validation of the analysis scheme and data processing approach

The goal of this research was to develop an analysis scheme to structure the study of required situation awareness and to develop an alternative approach to identify deficiencies of support of SA in cases where operators work with complex information systems. The analysis scheme does not only point out relevant aspects of SA, but emphasizes the relationships between these aspects. In order for the analysis scheme and data processing approach to be valid and valuable, they need to be applicable in real-life cases.

3.4.1 JUSTIFICATION OF THE LOGICAL PROPERNESS OF THE ANALYSIS SCHEME

Justification is required to scrutinize the logical stand of our theory and analysis scheme by showing satisfactory evidence. In our case it is not possible to provide empirical evidence for the properness of the proposed analysis scheme. Therefore, we need to find rational reasons for its properness. Rational reasons can be provided from the following three aspects: (i) the reasoning model is well-grounded to be logical, (ii) it does not have any internal inconsistence or incoherence, and (iii) it does not suggest illogical consequences when applied.

Concerning item (i), our reasoning is as follows. The knowledge on which the analysis scheme is based was constructed by a critical synthesis. It means that existing partial theories of situation awareness have been combined and transformed into the analysis scheme, as was shown in Figure 2.4. The derived components stand logical scrutiny in themselves as they originate from well tested theories. The way of combining them and putting them into context did not change their logical status. In order for the analysis scheme to be true, the combination of this added content, however, also needs to be consistent. The proposed analysis scheme introduces extensions of the sub-theories and adds relations among the different aspects. The order of the suggested analysis steps and the relations between the aspects may not lead to a conflict. For this reason we have to consider the issue of internal consistence or coherence, as required in item (ii) above.

The basis of our reasoning about the internal consistence of the analysis scheme is the information flow that is entailed by the analysis scheme. As it is shown in Figure 2.4, the analysis scheme does not introduce any reflexive or recursive relations that may lead to logical fallacy or incorrectness in the information flow. The proposed order of analysis steps is chronological and transitive. It is also unbroken semantically. The analysis scheme proposes to start with the analysis of the operator's goals and tasks. In the studies done by others, the analysis of both the goals and the tasks of the operators was considered a logical first step [5] [9] [19]. The information flow in the analysis scheme shows that information on the goals and tasks, as well as about the individual factors and the system factors is required to understand the MMIs. Information on goals and tasks should also be available before defining the information needs per task. The looping of the information processing between the SA knowledge and the SA assessment is of a local nature, having no influence on the analysis scheme as a whole. Actually, the following is happening here: The SA knowledge and the SA assessment are semantically interrelated. Therefore, when the SA knowledge is changed the SA assessment also needs to be updated. This loop does not block the total information flow.

Concerning the absence of illogical consequences when applied, earlier mentioned item (iii), our reasoning is as follows: In our case study, the proposed analysis scheme has been operationalized in the practice. Without a structured approach, N-ONM operators and SMEs were not able to clearly define the N-ONM required SA. Using the analysis scheme, we could generate a description of required SA for N-ONM tasks, which was considered logical and valid by both operators and SMEs. Application of the analysis scheme thus showed positive empirical results. It showed that the proposed order of steps is suitable to define required SA. The gained insight in required SA was useful to develop an observer checklist, observer evaluation form, and self-rating evaluation form to study the deficiencies of current SA support systems. We conclude that the scheme was implementable in practice and helped in the study of deficiencies of current MMIs. Therefore, imposing the principle of reasoning with consequences, we may claim that if the proposed analysis scheme works well in practice, then there is no reason to assume that the knowledge included in the analysis scheme is not proper or illogical.

3.4.2 VALIDATION OF THE PRACTICAL APPROPRIATENESS OF THE ANALYSIS SCHEME

The practical case study showed that application of syntactic-semantic data processing of CTA and observational research data aided identification of different types of deficiencies. Table 3.3 provides an overview of the number of syntactic and semantic groups which were identified through analysis of CTA and observational research data. The row “CTA and observation” shows the number of groups identified through combined use of CTA and observational research data. In total, 30 deficiencies were identified.

Neither the analysis of CTA data nor the analysis of observational data allowed us to discover all 30 deficiencies of supporting SA. Two of the identified deficiencies were not recognized through analysis of CTA data:

- Operator experiences physical discomfort, which decreases operator's mental capacity for SA knowledge
- System does not support efficient insertion of information, which hinders SA assessment

The questionnaire used during our observational research specifically asked operators to what extent they experience physical discomfort. Three of the six observed operators mentioned five forms of physical discomfort in total which hindered task performance. The used CTA methods did not address physical discomfort. Within the self-rating observation data, both the answers to open questions and the rating of occurrence of deficiencies revealed that insert of information can be time consuming, partly because systems require operators to answer what they call 'irrelevant questions'. Although CTA did not explicitly address insert of information, this deficiency is related to questions about imperfections of systems and cumbersome working methods, which were part of the knowledge audit interviews. Inefficiency in insert of information, however, was not mentioned in the CTA data.

Table 3.4 shows the number of deficiencies which were assigned to the different types of classifications in step 8 of the syntactic and semantic processing. The 'Overlap' column shows the number of deficiencies which were identified through both analysis of CTA data and analysis of observational research data. For most types of classification, the observational data in this study allowed us to identify approximately 50% of the deficiencies

Table 3.3 Number of identified syntactic and semantic groups

	Syntactic groups	Semantic groups
CTA data	86	28
Observational data	32	11
CTA and observation	101	30

Table 3.4 Classification of identified deficiencies

	CTA data	Observation data	Overlap
Circumstances	11	7	6
Informing	10	5	5
Workflow	6	2	1
Cooperation	4	3	3
Ability	2	1	1

which we also identified with the use of CTA data. For deficiencies related to workflow, however, there was little overlap between deficiencies identified using the two different data sets.

Beside the fact that analysis of observational data did reveal two deficiencies which were not identified through analysis of CTA data, we can also argue why observational data does complement CTA data. CTA in essence focusses on cognitive aspects. If applied in the study of operators' SA, this implies a focus on situation awareness assessment and the support of information retrieval and processing. Our results show that this focus incorporates the risk of overlooking deficiencies which are not directly related to situation awareness assessment. In our case, analysis of CTA data did not reveal that physical discomfort limited operators' SA knowledge and inefficient insert of information hindered SA assessment.

In general, CTA data does not sufficiently address the influence of parallel activities which do not directly relate to SA, but do affect the mental capacity available for SA. In contrast to CTA, observational research focusses on observation of manual activities over mental activities. Observational research studies the total of performed tasks. Compared to CTA, it has limited potential in identifying deficiencies related to mental processes. An advantage of observational research, however, is that it does incorporate the study of parallel activities, including those which are not directly related to operators' SA. Combined use of CTA and observational research data therefore increases the chance in exploring deficiencies. We can conclude that the use of both sources in parallel increases the success of exploring deficiencies. In addition to the overlap, the two sources complement each other.

To validate the total list of identified deficiencies, we presented them to eleven SMEs. They confirmed that the list was accurate, recognizable and as far as it is known complete. The presented research does not provide us with an exact answer to the question to what extent a structured analysis of observational research data and CTA data can aid researchers to identify deficiencies, because the total set of deficiencies is unknown. The results, however, do demonstrate that the proposed method can be used to detect a moderate number of different types of deficiencies. Taken together, the results show that the syntactic and semantic processing of CTA data and observational research data is a suitable method to identify deficiencies of supporting SA in cases when operators remotely control an environment.

3.5 Conclusion

This chapter has presented a structured approach which allows researchers to use observational research data and CTA data to detect and categorize deficiencies of supporting SA. The results showed that analyzing these data sources aided identification of five different types of deficiencies, e.g. (i) circumstances deficiencies, (ii) informing deficiencies, (iii) workflow deficiencies, (iv) cooperation deficiencies, and (v) ability deficiencies. The presented approach supports analysis of sources of SA errors in cases in which the study of accident reports and the use of realistic simulated scenarios is not an option. Both logical reasoning as well as our research outcomes showed that CTA data and observation data are best analyzed in parallel if the aim of the research is to generate a thorough overview of the deficiencies in supporting operators' SA.

The applied analysis scheme was derived from commonly accepted and well tested theories which were developed and applied in several command and control domains, such as aviation, air traffic control, and process control. Combined analysis of CTA data and observational research data following the presented structured approach assumedly is profitable in these analogue contexts as well. Further application of the scheme in research practices in these domains may help to develop more insights in its advantages and limitations.

Three-quarter of the identified deficiencies were related to how the user interfaces support human information processing. This finding confirms our initial assumption that a logical next step is to study potential user interface concepts to overcome the identified deficiencies. Several of the identified deficiencies were related to the fact that operators require a large amount of information. For this reason, information engineering needed to be considered as an important aspect of designing user interfaces to better support operators' SA assessment.

3.6 References

This chapter is based on:

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CHAPTER 4

Research Cycle 3

DEFINING USER INTERFACE CONCEPTS TO OVERCOME THE IDENTIFIED DEFICIENCIES

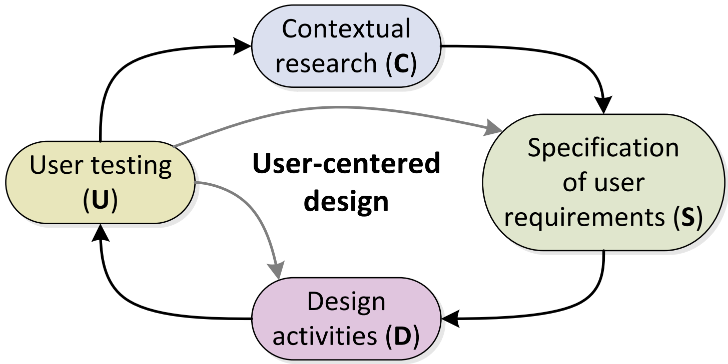
In chapter 3 we identified three groups of deficiencies of current support of nautical operational network management (N-ONM) operators' situation awareness (SA). To overcome these deficiencies, this chapter investigates an information engineering (IE) approach to designing user interfaces (UIs) to support operators' SA. The design of high quality UIs of complex systems requires to investigate the man-machine interactions and to understand the users' needs to enable designing systems with high usability. Complex systems comprise large amount of information which may relate to each other. Designing such systems, therefore, requires a structured approach for information handling. Section 4.1 presents the user-centered design (UCD) approach which we applied to acquire user input for improving product usability. The UCD process, however, does not provide a structured approach for handling large amounts of information in systems. For this purpose, we introduced formal information modeling techniques in section 4.2. Aiming at overcoming the identified deficiencies, we applied three different techniques to develop three theoretical concepts: a coherent (section 4.3), an integrated (section 4.4), and a context-dependent adaptable (section 4.5) UI. To evaluate the usefulness of these concepts, section 4.6 demonstrates the feasibility of the concepts by applying them to the UI concept developed through UCD in section 4.1. Section 4.7 relates our research approach to other studies presented in UI literature. In the conclusion in section 4.8 we evaluate how combined use of UCD and formal modeling aids designers to overcome deficiencies of complex systems.

4.1 User-centered design to support operators' situation awareness

The basis of UCD is to apply structured methods for acquiring user input in iterative design cycles. Each cycle consists of contextual research, specification of user requirements, design activities, and user testing, see Figure 4.1 [1] [2] [3] [4]. We applied UCD to design a UI to better support SA of operators responsible for nautical operational network management. Our UCD approach consisted of three design iterations that started with contextual research. In each cycle we included two types of user testing. Firstly, we tested design results with an expert group. The expert group consisted of six experienced operators, four nautical traffic management advisors, and one UI design expert. When the expert group and designers agreed upon the results of the design activities, the results were presented to an operator sounding board. This sounding board consisted of 50 volunteers. In Figure 4.1 these extra steps are presented as a loop between design activities and user testing. In the third iteration, extra specification of user requirements, design activities, and user testing was required before the detailed design was elaborated enough to present to the sounding board. This loop is also visualized in Figure 4.1. An overview of the applied UCD steps is given in the table presented in Figure 4.1.

In the first iteration we developed a set of design principles together with a sketch design, see Figure 4.2. The second iteration resulted in an overview of information needs per activity and a conceptual design, see Figure 4.3. The third iteration resulted in a detailed design 1 and 2, with use cases that were implemented in a clickable prototype. Figure 4.4 shows a screenshot of detailed design 1. The use cases of detailed design 1 and 2 are given in Appendix VI and VII, respectively. Figure 4.5 and Appendix XIII show screenshots of detailed design 2. For a more detailed overview of the development and evaluation of the sketch design, concept design, detailed design, and use cases, see [5]. The design principles and overview of user requirements are discussed in more details in [6].

Forming a team, five designers were responsible for the design activities and prototype development. They were supervised by the PhD candidate.



Applied user-centered design steps
C: Define goals & Tasks (see section 3.2.1)
S: Specify required MMI areas and design philosophy
D: Sketch design
U: User testing of sketch design with expert group
D: Update sketch design (Figure 4.2)
U: User testing of sketch design with operator’ sounding board group
C: Define information needs (see section 3.2.2)
S: Specify information needs per MMI area
D: Conceptual design
U: User testing of conceptual design with expert group
D: Update conceptual design (Figure 4.3)
U: User testing of conceptual design with operator’ sounding board group
C: Observation and interviewing to gain understanding of current system use
S: Use case development and specification of user requirements
D: Detail design 1 with use cases implemented in clickable prototype (Figure 4.4 and Appendix VI)
U: User testing of detail design 1 with expert group
S: Use case development and specification of user requirements
D: Detail design 2 with use cases implemented in clickable prototype
U: User testing of detail design 2 and use cases with expert group
D: Update use cases and detail design 2
U: User testing of detail design 2 with operator’ sounding board group
D: Update use cases and detail design (Figure 4.5 and Appendix VII)

Figure 4.1 Iterative design cycles of the user-centered design approach

The design team met with the expert group bi-weekly to discuss design decisions. The knowledge of the experts was used as kind of 'walking encyclopedia'. Once the expert group and design team agreed upon the result of the design activities, the designs were presented to the operator sounding board. The sketch design was presented using a PowerPoint presentation. The conceptual design was presented as pictures on an actual workplace. Detail designs 1 and 2 were presented as interactive prototypes on an actual workplace, after which the experts and operators were able to carry out the use cases. The members of the expert team were present during the sounding board sessions to observe how the concerned operators performed in the use cases. The insights gained by these observations were taken into account by the experts at their evaluation of the designs. All comments made during user testing were logged and the design decisions made based on these comments were reported back to the sounding board as well as to the expert group.

A large number of deficiencies identified in the previous chapter was due to the limitations of the current system interfaces to support human information processing. The UCD approach aided to identify which information the

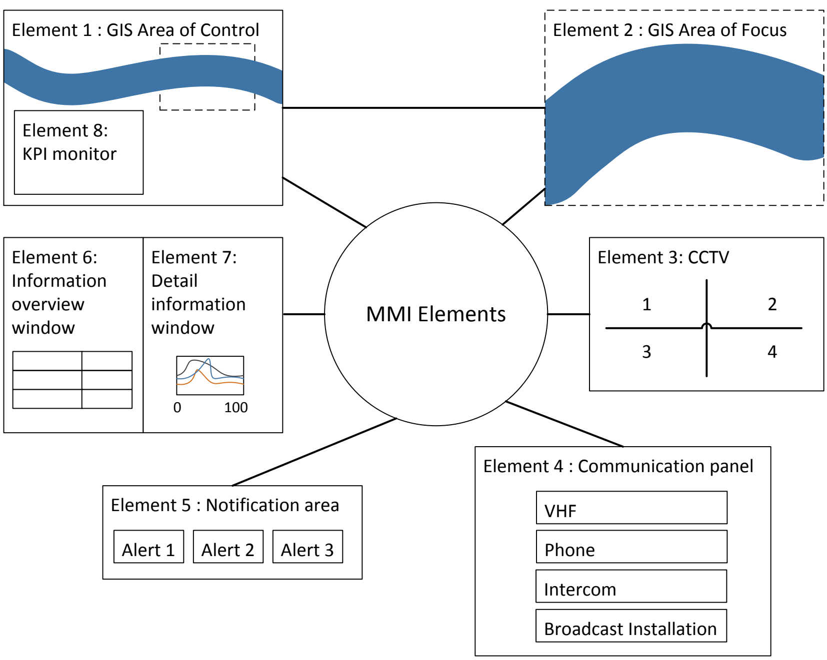
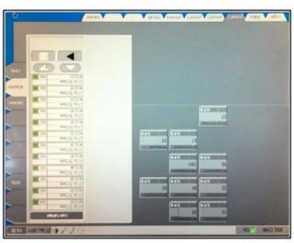


Figure 4.2 Sketch design



Element 4:
Communication panel

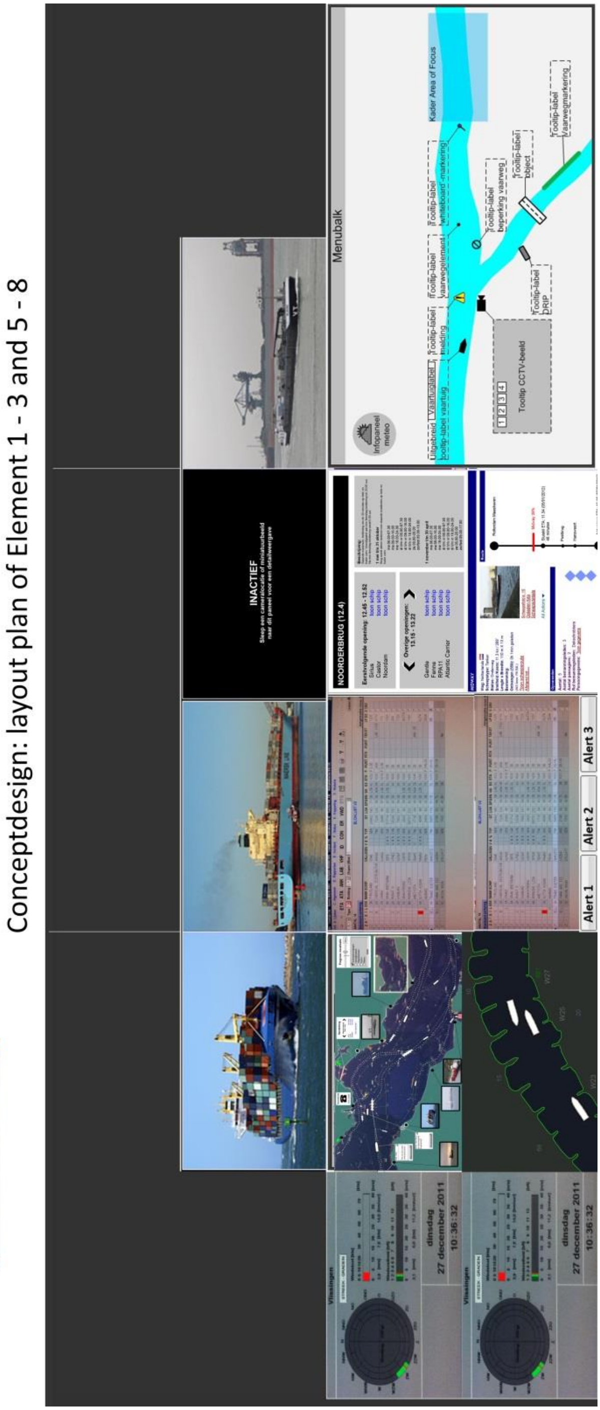


Figure 4.3 Conceptual design

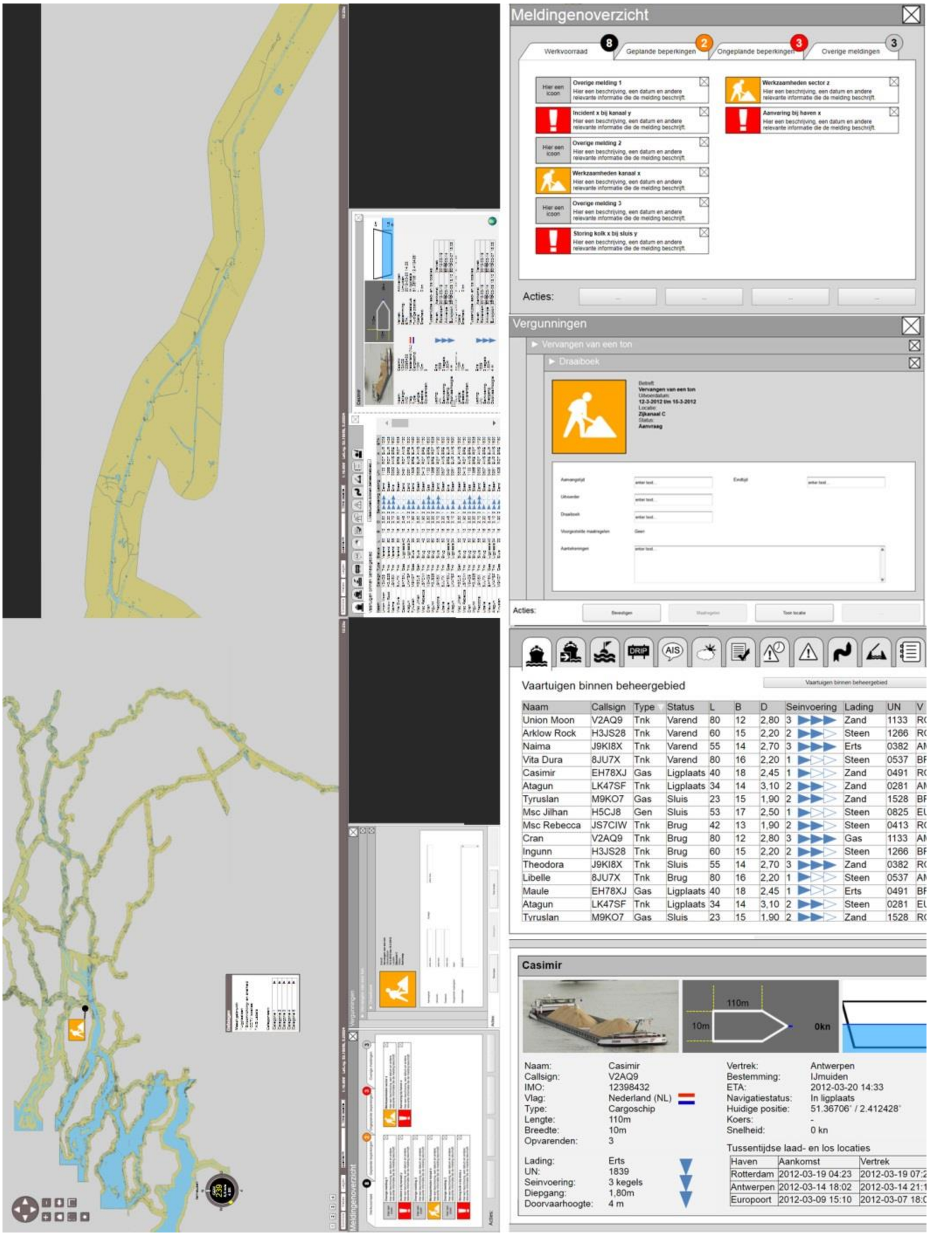


Figure 4.4 Screenshot of detailed design 1 (left) and enlarged details (right)

operators needed to reach their goals. It, however, did not support the designers in specifying how the system handles these large amounts of information. The completed steps of UCD resulted in an UI design which at first sight helped to overcome the identified deficiencies. The look and feel of the UI design was evaluated positively. Evaluation of the interactive prototypes, however, showed that UCD did not sufficiently aid to overcome the identified deficiencies of how the system interfaces support human information processing. In the next section we discuss how some dedicated approaches and principles of IE were used to overcome the identified deficiencies.

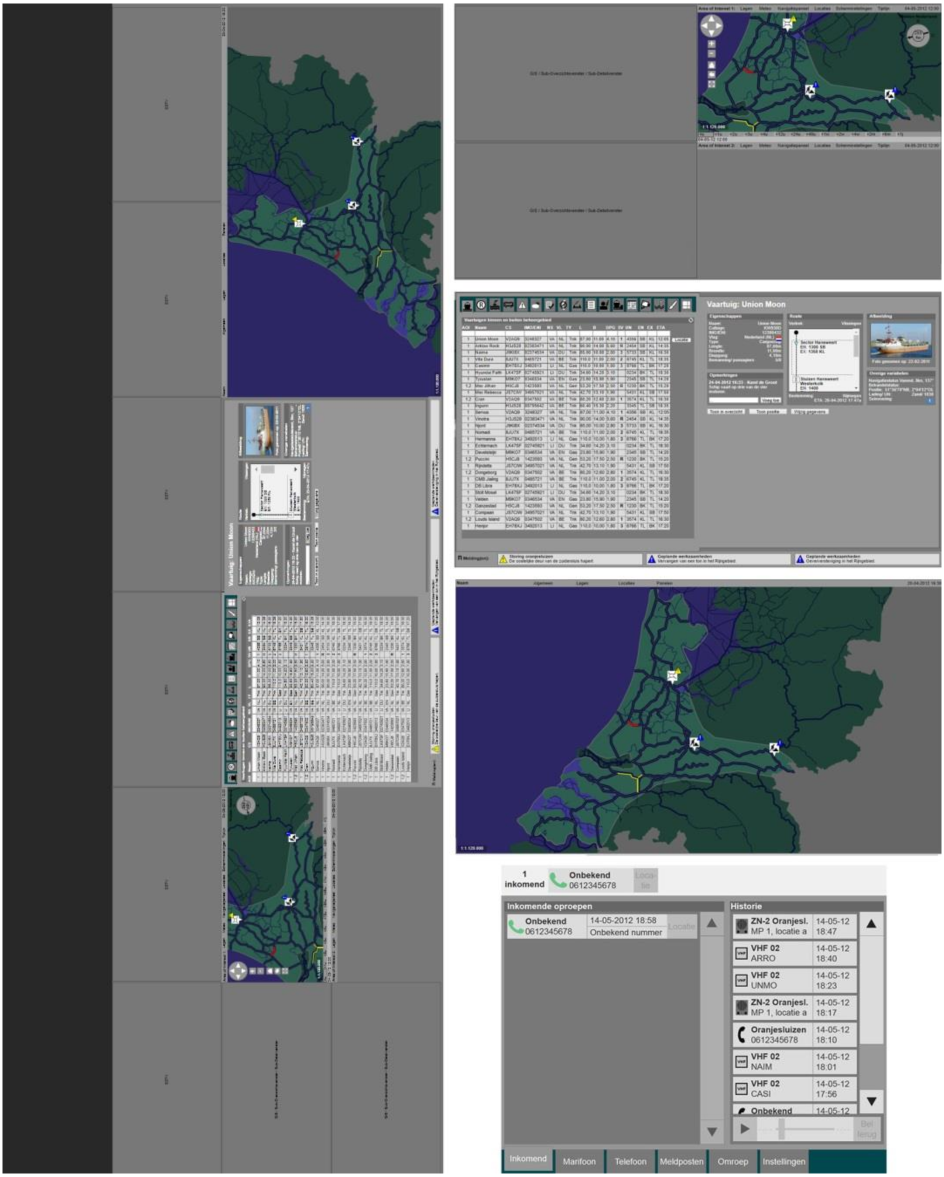


Figure 4.5 Screenshot of detailed design 2 (left and enlarged details on right sight) and communication panel (bottom right)

4.2 Formal information modeling for user interface design

In the previous chapter, four groups of deficiencies related to supporting human information processing for N-ONM tasks were identified (D.1. – D.4.). In chapter 2 we identified that human information processing can be improved by supporting (i) operators' perceptual capabilities, (ii) cognitive processing for information interpretation, (iii) the development of suitable schemata or prototypical situations in long-term memory story, and (iv) effective use of working memory. Effective visualization of data helps users in perceptual and cognitive processes to interpret and understand the presented information [7]. Visualization of large amounts of information, however, raises challenges for designers of complex information systems.

IE offers methodologies for designing complex information systems. These methodologies aid designers in handling large amounts of information by offering a set of formal modeling methods. These methods allow to specify the information structures and interrelationships for a system. The overview of deficiencies showed that the same information in current systems can be accessed at different locations, that systems show contradictory information, and that the priority of information is not visible. Having considered the opportunities offered by IE to overcome these types of deficiencies, we decided to address the identified deficiencies from an IE perspective. This reasoning was reinforced by some important observations:

i. different UIs used simultaneously may lead to conflicting, confusing, and unclear information
ii. systems may display disjoint, fragmented, and redundant information entities without visualizing the interrelationships of the information entities
iii. UIs may present information independent of the context, while the information needed by operators is context-dependent.

IE methods can be used in different design phases. To support detail design phases, various formal modelling techniques have been proposed to ensure correct implementation of design rules. Examples of such design rules are (i) rules of consistency between UI components [8] [9], and (ii) rules of modelling context conditions and UI adaptations [10] [11]. In conceptual design phases, methods support structured analysis of the system to be designed. For example, an abstraction hierarchy combined with a goal-means analysis is useful to define the relationships between information elements, which should be represented explicitly in the UI design [12]. Abstraction hierarchy is a technique proposed by Rasmussen [13]. It applies five abstraction levels to describe why certain components are needed.

Abstraction-based modeling provides insight in how the individual system components contribute to a particular functionality of the system. It is based on taxonomies of usability heuristics and types of automation as well as low-level design guidelines for enhancing interface features [14]. Though these approaches can give insights into the workflow of users and into the structure of current systems, they do not offer methods that help designers to optimize information flows within specific tasks. They facilitate the exploration of requirements, but they do not support the UI designer in modeling and specifying the UI itself [15]. A recent attempt on extending cognitive task analysis and hierarchical task analysis with failure mode and error analysis, aimed to integrate work domain, task, and social organization into a single framework to form a comprehensive human-factors analysis required for UI design [16]. Although this holistic analysis framework was found to be effective in designing a maritime navigation tool, it intensively relied on the creativity of designers and did not offer a procedure to come from analysis to optimal design.

In this work we aimed to develop a method which supports designers both in analyzing relationships between information elements and in specifying UI design. We used the identified groups of deficiencies together with formal modeling to support structured IE in designing UI concepts. By using these methodologies at developing the UI concepts, we kept our solutions application domain independent, in order to enable their applicability in similar contexts.

4.3 Defining the coherent user interface concept

In remote control environments software tools represent knowledge about the physical world. Chapter 3 showed that proper information visualization is required to allow operators to correctly access and process the information presented by the systems and to obtain the necessary SA. More specifically, the collected research data indicated that differences in the form of information visualization by the different systems used for the same tasks may lead to errors in SA. In our study we found several deficiencies of current systems and their man-machine interface:

i. Conflicting information due to different data sources: For example, different systems showed overlapping information of which the content could conflict in case of different data sources. Data could be outdated, incomplete or incorrect.
ii. Confusing information due to different ways of representing similar or the same data and information. For example, system I used a downwards pointing vertical arrow (↓) to indicate that a vessel is traveling downstream while system II used a left pointing horizontal arrow (←) to indicate that a vessel is traveling downstream.
iii. Confusing information due to similar visualization of different information. For example, system I visualized vessels carrying dangerous cargo with a red icon, while system II used a similar red icon to represent that the vessel's certificate has expired.
iv. Indistinct information due to unstructured presentation of large amount of information. For instance, a long list of vessel names which required a lot of scrolling and cluttered UI which reduced SA.

To overcome the above mentioned deficiencies, we developed the concept of a coherent user interface, which we defined as follows:

> *A coherent user interface is a logical, consistent, orderly, and harmonious interface. If there are multiple associated interfaces, then they together form a coherent whole.*

A coherent UI achieves coherency in terms of the information contents and in the way of presentation of this content on the screen. Although this design principle is simple in theory, applying this in cases of complex information systems is not. In fact, the designers in our case study already aimed for a coherent UI and user testing included evaluation of the achieve coherency. UCD, however, did not provide the team with structured tools to design for and to evaluate the coherency. It therefore is unclear to what extend the UI design developed in Section 4.1 is already a coherent UI.

We found that the information processing concerning a coherent UI can be modeled and represented by applying operations of set theory. The use of set theory enables to handle information sets to formally map pieces of information to parts of the system; determining whether or not that information entity (object) is a member of that set (information window) [17]. The content of every UI window can be converted to information sets per window; every interface entity related to a system can be described as the element of a set. In this way, the total information content of a system can be described as the union of all sets, $U = A \cup B \cup \ldots \cup Z$, where '$A = \{\ldots\}$' is the subset of information entities belonging to window I. In the simplest case, the different UI windows do not display the same information and the information presented in the different windows can be described by disjoint sets ; $A \cap B \cap \ldots \cap Z$ is an empty set, $\emptyset$. In order to achieve coherency between the UI windows, we propose that the same information visualization rules need to be applied to all sets. In cases of intersection of sets, $A \cap B \cap \ldots \cap Z$ is not an empty set, additional rules are required to maintain coherency between the UI windows.

Set theory facilitates to mathematically codify principles of valid reasoning, and as such can be used to model how the information entities are handled by the system [18]. Using formal modeling based on set theory allows designers to make design decisions explicit and to maintain an overview of relationships among information entities required for design decisions. As such, it helps designers to apply their own expertise by translating design decisions to explicit rules. The rules required to achieve a coherent interface need to address each of the four aspects of coherency, i.e. logical, consistent, orderly, and harmonious. These four aspects are related to coherency in terms of both information contents and the way of information presentation. Set theory enables to formalize these aspects.

Logical: A system's UI is logical, if and only if logical operations exist between the information entities of any subset of the system. Commonly used logical relations include; not ($\neg$), and ($\wedge$), or ($\vee$), if … then ($\rightarrow$), and if and only if ($\leftrightarrow$). For instance, if information entity I_a implies information entity I_b, so that $I_a \rightarrow I_b$, and information entity I_b implies information entity I_c, $I_b \rightarrow I_c$, then this implies that $I_a \rightarrow I_c$. For example, if 'wind-force' > 7 then vertical lift bridge is 'not operational' and if vertical lift bridge is 'not operational' then waterway availability is 'obstruction' infers that if 'wind-force' > 7 then waterway availability is 'obstruction'. If information related to obstruction of the waterway is to be highlighted, then this means that wind-force needs to be highlighted if it has a value > 7.

Consistent: A system's UI is consistent, if an only if any information entity I_k that is element of multiple subsets (A, B, …, Z), has the same information content and representation attributes in all subsets at all time. If changes to an information entity are made in window I, representations of the same information element in other window(s) are adjusted accordingly. If a red triangle has meaning 'x' in window I, than a red triangle also needs to have meaning 'x' in window II.

Orderly: A system's UI is considered to be orderly, if and only if, spatial and structural arrangements of a subset of entities across and within multiple windows follow the same principles and rules. For example, information entities are listed in order of appearance; (a) vessels are listed in the order of their estimated time of arrival in the area of control, (b) traffic measures are listed in the order of their start time, and (c) log information is listed in the order of time of entry. Furthermore, all lists which are ordered based on time of appearance are displayed in the same structure. For example see Figure 4.6.

Time	Name	Features			
12:00	Alex	L. 80	W. 9	D. 2.5	H. 1.2
12:00	Speed limit Waal	Max 5.0 m/s			
12:00	Maintenance Lock I	Door renewed			

Figure 4.6 Orderly structure of information

Harmonious: A system's UI is harmonious, if and only if, content and properties of information entities, such as syntax, semantics, color, font type, and graphical styles, are related to or complement each other. For instance, colors in the different windows have the same saturation, but do not have the same color if the information entities have a different meaning. For example see Figure 4.7.

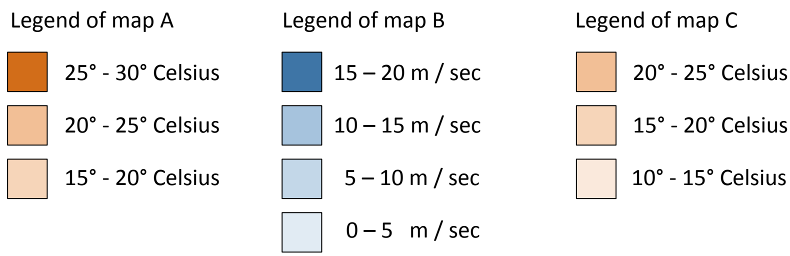


Figure 4.7 Example for a harmonious color use (harmonious and consistent in structure, saturation, and color)

4.4 Defining the integrated user interface concept

Current nautical traffic management systems mainly display disjointed information elements, supporting perception of separate information entities or Level 1 SA. The previous chapter showed that with such a system UI, operators experience difficulties in having and maintaining a complete overview of a large area of control. Integration (logical combination) and ultimately semantic synthesis is required to resolve this issue. Logical combination of disjoined information entities facilitates comprehension of the current traffic situation or Level 2 SA [19]. Thus, in order to enable operators to form a holistic picture of the traffic situation and the environment, we developed the concept of an integrated user interface, which we defined as follows:

> *An integrated user interface uses information fusion and capitalizes on content interactions of multiple user interface windows. Interrelated user interface contents are structurally integrated as such that user interface windows support specific tasks.*

An integrated UI reduces the disorganized, fragmented and redundant pieces of information as much as it is possible. Designers can address these issues without the use of formal modeling. In cases of complex systems, however, relevant fusion and interaction opportunities are easily overlooked. A more structured approach aids designers to develop an integrated UI. A structured approach for designing an integrated UI requires specifying the logical and semantic interrelationships of information entities and the functional interaction between information windows. We found that symbolic specification of these relationships needs the formalism of both set theory and common graph theory.

Integration in an integrated UI is task driven; information entities which are required for the same tasks are clustered such that each UI window supports specific tasks and/or activities. Therefore designing an integrated UI requires defining information needs as sets per task. In Chapter 3 we described task analysis steps required to generate an information needs overview. As in the case of coherent interfaces, the information contents (pieces of information) required for each task and the overlap of information (i.e. the information which is needed for multiple tasks) can be specified by the means of set theory, see Figure 4.8.

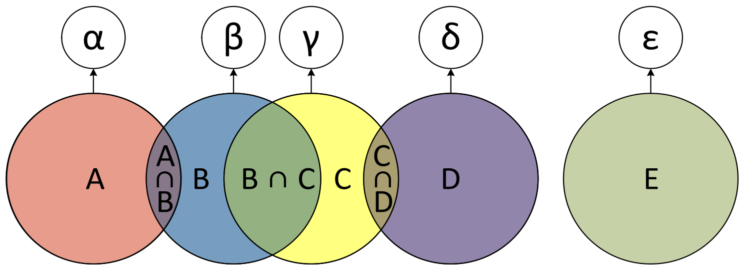


Figure 4.8 Information sets (A – E) per task (α – ε)

The use of graph theory enables to specify the functional relationships between the resultant information sets and allows to represent the fusion of information entities in an information needs graph (ING). Information entities and information subsets can be represented by vertices and the relations between them can be represented by edges of planar graphs. Various annotations can be attached to edges and the orientation of the edges can specify the direction of relationships [20]. Edges between vertices can be one-way directed, two-way symmetric directed or two-way asymmetric directed to express the nature of logical relations. This is shown in Figure 4.9.

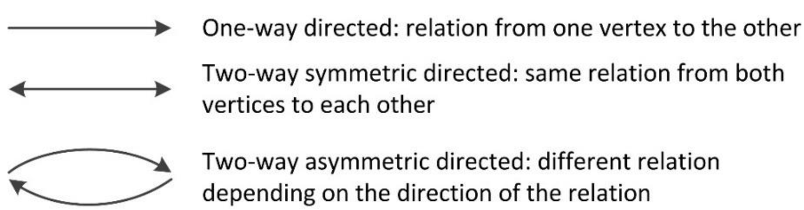


Figure 4.9 Three types of edges used in graph theory

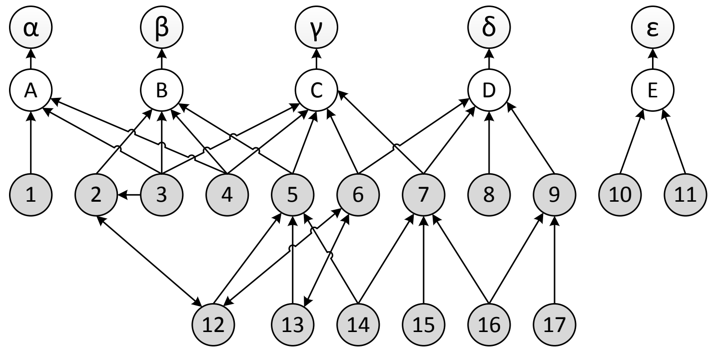


Figure 4.10 Information needs graph, representing which information entities (1 – 17) are required for which task (α – ε)

If the formalism of graph theory is used, edges can specify the nature of information fusion. For example, as shown in Figure 4.10, the set of vertices adjacent to vertex 9 is N(9) = {16, 17, D}. The two edges {16, 9} and {17, 9} are pointing towards 9. The edge {9, D} is pointing outwards. This means that 9 is a product of 16 and 17 and that 9 is part of subset {D}. For each information entity, {X}, having edges pointing towards its vertex, it needs to be defined how 'x' is calculated. For instance consider {9} as vessel location in an hour, {16} as current vessel location and {17} as vessel speed over ground in m/s. The element 'x_1' of set {9} can be calculated using the elements of set {16} and (17} with the formula $x_1\{9\} = x_1\{16\} + x_1\{17\} * 3600$. In this example the relation is one-way directed: {9} is not used to calculate {16} or {17}. The relation can also be two-way symmetric directed, for example if {2} is the headway, the vertical space available to allow passage under a fixed object like a non-movable bridge, {3} is the fixed height of the lower side of the object and {12} represents the water level, then $x_1\{2\} = x_1\{3\} - x_1\{12\}$ and $x_1\{12\} = x_1\{3\} - x_1\{2\}$. If either {2} or {12} is known, then the other variable can be calculated. Both variables are possible to measure.

Consecutive edges connecting multiple vertices are called a path, which aid identification of logical groups of sets. In the above example, if {2} is changed, then {12} changes, which in turn also influences {5} and {6}. Analyzing relations between subsets in the ING helps designers to look for possibilities for information fusion and for clustering these entities in a UI window or in adjacent windows. For example the ING in Figure 4.10 shows that B ∩ C = {3, 4, 5} and B \ C = {2, 6, 7}. Additionally, the paths in the ING show that both B and C require availability of {12, 13, 14}. The two-way directed edges show that changing {2} or {6} results in changing {12} and as a consequence that changing {2} results in changing {6} and vice versa. This insight can be used for underpinning decision making of expert designers. In this example the ING indicates a meaningful integration of {B} and {C} in one window displaying {2, 3, 4, 5, 6, 7}. Design expertise is required to weight this and other possible design solutions. Resulting design decisions can be represented in a content integration graph (CIG). For example, integration of {B} and {C} in one window II is displayed in the CIG in Figure 4.11.

If the network contains subgroups without a path between them, then each subgroup could be presented in a different UI window. For example, in Figure 4.10: $A \cap E = \emptyset$, $B \cap E = \emptyset$, $C \cap E = \emptyset$, $D \cap E = \emptyset$ and $N(E) = \{10, 11\}$. The principle that UI windows of an integrated UI support specific tasks results in the presentation of information sets {10} and {11} in a separate window, visualized as window IV in Figure 4.11.

In the in-between cases, where there are certain relations between subgroups but not many, it depends on the importance of the information for the task execution where information is displayed. In general, information is displayed in the window with the most relations with this entity. If both tasks strongly rely on the information entity, than it can be displayed in both windows. If this is the case, then the representation needs to be kept consistent. For example in Figure 4.10: $C \cap D = \{6, 7\}$ in which {6} has multiple relations with other

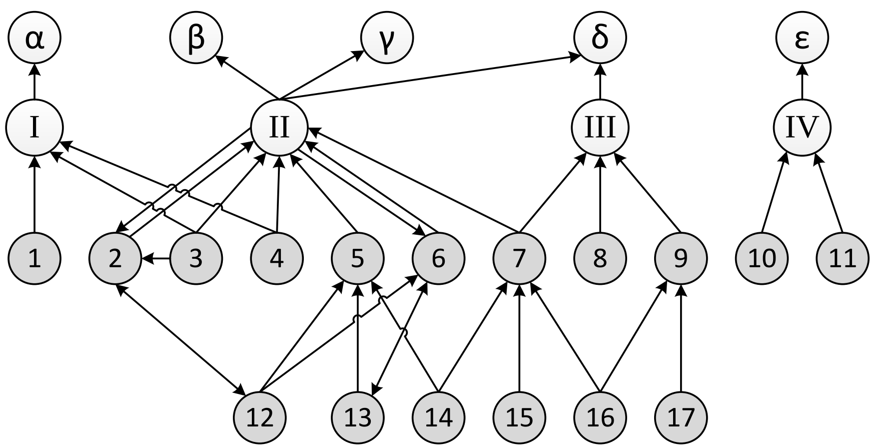


Figure 4.11 Content integration graph, representing which information entities (1 – 17) are presented in which window (I – IV) and which window supports which tasks (α – ε)

entities related to {C} and no other relations with entities related to {D}. {7} has relations with both entities related to {C} and related to {D}. Here it can be logical to display {6} in window II only and {7} in both window II and III: II displaying {2, 3, 4, 5, 6, 7} and III displaying {7, 8, 9}, see Figure 4.11. The presentation of {7} in the different windows needs to be consistent. Since {6} is needed for task(s) which are also supported by window III, window II and III should be placed next to each other.

Directed edges in the CIG visualize how user's actions in an integrated UI can result in system actions in the same window and/or in other window(s). If an information entity can be adapted in a UI window, than this can be represented by a two-way symmetric directed edge between the window and the information entity vertex. Changes in information content can result in changes of related content. See {II, 2) and {II, 6} in Figure 4.11. If the content of {2} is changed in window II, then this affects {12}, which in turn influences {6}.

In an integrated UI, user's interaction with displayed information can influence information presentation elsewhere in the UI. For example, clicking a vessel's name in one window can trigger highlighting all pieces of information that are related to this vessel in other windows. Therefore, designing an integrated UI requires to identify useful interactions between windows. Interactions can be useful in cases where windows present the same information entities and/or when windows support the same task. Although all these relations are presented in the CIG, we experienced that this graph can be too complex to support a structured evaluation of relevant relations, especially in cases of information intensive systems. The relations between windows can be presented in a more clarifying way by translating the CIG representation into a windows relation network (WRN).

To represent the relations between two windows, all windows can be presented as vertices in a WRN. Weighted edges can be used to present the amount of information entities and tasks shared by two windows, see Figure 4.12. The weights equal to the number of information entity vertices and task vertices that windows share in the CIG. Two windows share a vertex if they both have a path connecting them with this vertex. Paths follow the direction of the arrows. For example in Figure 4.11: {II, 2, 12, 5} is a path, but {5, 12, 2, II} is not. The paths {7, II) / {7, III), {14, 7, II} / {14, 7, III}, {15, 7, II} / {15, 7, III}, and {16, 7, II} / {16, 7, III} represent the 4 information needs vertices shared by the windows II and III. The paths {II, δ} and {III, δ} represent the one task shared by these two windows.

The WRN representation facilitates designing the windows interaction graph (WIG). Each edge in the WRN represents potential useful interactions. Therefore, each edge can be evaluated by expert designers to decide whether one or more useful interactions in relation to this edge can be identified. Design decisions about useful interactions can be specified as edges in a WIG. Edges in the WIG can be any of the types shown in Figure 4.9. For instance see the simple example shown in Figure 4.12. In this example a specified user action in window I results in system action(s) in window II. User action in window II does not result in system action(s) in window I, but does result in system action(s) in window III and IV. The interaction between window III and IV is two-way asymmetric; a user action in window III triggers different system action(s) in window IV than a user action in window IV triggers in window III. The shown relation between window II and IV is two-way symmetric. This means that a user action in window II triggers the same system action(s) in window IV as that this user action in window IV triggers in window II.

a. Windows Relation Network (WRN) **b. Windows Interaction Network (WIN)**

Figure 4.12 **a:** Windows relation network representations in which numbers in italic blue represent the weights of shared information entity vertices and the numbers in bold red represent the weights of shared task vertices.

b: Window interaction network representations of the relations between windows in an integrated UI.

4.5 Defining the context-dependent adaptable user interface concept

Chapter 3 discussed the task, system, and operator dependency of required SA. It was argued that changes in context influence the required SA of the operators, as well as the required support of SA. Current system interfaces, however, typically present information independent of the context. Therefore, at the development of a third alternative of supporting operator's SA, we considered a UI that is able to automatically adapt on the basis of changes in the context; a context-dependent adaptable user interface. We defined this concept as follows:

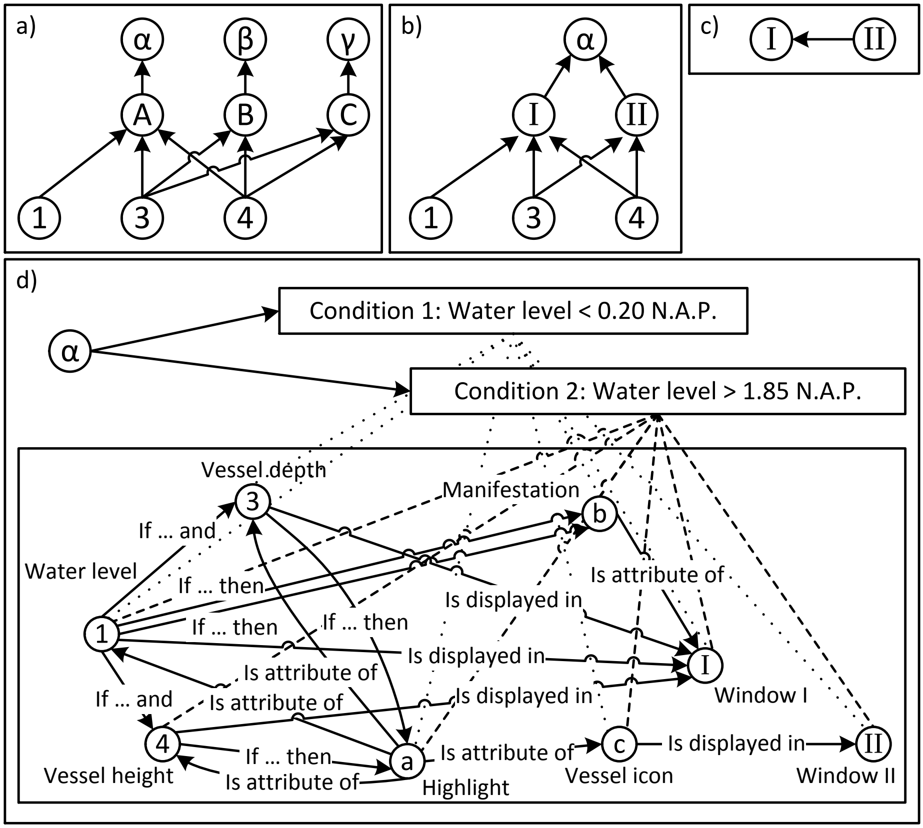
> *A context-dependent adaptable user interface captures context information, assesses the implications of context, and accordingly adapts the interface content and composition to best support the pertinent tasks in the given context.*

A context-dependent adaptable UI uses context-dependent decision making to adapt UI content according to the evaluated context. Designing efficient context-dependent information visualization is a complex design task. Designers need to have deep insights in (i) the operators' goals and tasks, (ii) the context in which operators pursue their goals and execute their tasks, and (iii) how information elements relate to these aspects. IE can aid designers in analyzing and specifying relevant context-dependent adaptations.

When applying a structured IE approach, context can be captured as an ordered set of information, which includes both descriptive and prescriptive elements. The descriptive elements of context describe the total of semantic relations between information entities, which play a role in a particular situation. The prescriptive elements of the context define the conditions relevant for context-dependent decision making. At modeling the constructs of context information, we found that we could use semantic network (SNW) formalism to correctly and uniformly represent both the semantic relations and the decisional constraints. A SNW representation allows mapping of both the interface composition entities and their attributes (descriptive information entities), and the decisional constraints and assigned values (prescriptive context information entities) in a context-dependency graph (CDG).

Mathematically, a SNW is specified as a labelled directed graph of interconnected vertices. The semantic relationships between the vertices are captured by directed and labelled edges [21]. The entire structure of the edges carries the meaning of the interconnections of all information entities, represented by the vertices. Examples of relations that can be defined between vertices of a SNW are: (i) taxonomical (c is an X), e.g. ‘obstruction of a waterway’ is a ‘priority 1 event’, (ii) manifestation (1 active in duration Y), e.g. ‘prognoses information’ active in duration ‘priority 1 event’, and (iii) conditional (if $\{\neg\}a \wedge \{\neg\}b \wedge \{\neg\}c$ then $\{\neg\}X$), e.g. if there is no ‘obstruction of a lock’, and no ‘obstruction of a bridge’ and no ‘obstruction of a waterway’, then there is no ‘priority 1 event’. These types of relations can be used to describe the information content. In other words, they specify what has to be displayed (i) under a specific context condition (why), (ii) at a given time (when), (iii) in a relevant UI window (where), and (iv) in a particular manner (how).

The specification of the interrelationships of information entities and the functional interaction between the information windows, as proposed in designing an integrated UI, can be used as a starting point at designing a CDG. Paths in the ING, CIG, and WIG graphs can be used to determine which information entities and windows are relevant for a given task considering the work context. A simple example is given in Figure 4.13d, which shows the CDG of a given single task, α. Let us consider this task α as “inform skippers about restrictions due to extreme water levels”. Water levels can either be too low or too high for vessels to be able to use the concerned waterway, depending on their depth and height. The information entities ‘Water level’ {1}, ‘Vessel depth’ {3} and ‘Vessel height’ {4} are descriptive elements of the context with respect to task α, as can be identified using the relevant part of the developed ING. This is shown in Figure 4.13a. The pertinent CIG indicates that these entities are visualized in Window I and II, (see Figure 4.13b). Defining the context of task α also requires to prescribe what semantic relations are implied by the attributive values of the descriptive elements. For example, if water level < 0.20 N.A.P, then vessels with a depth > 0.50 meter cannot use this waterway. If the water level > 1.85 N.A.P., then vessels with a height > 1.25 meter cannot use this waterway. (In the mentioned inequality expressions, N.A.P. is the reference height Normaal Amsterdams Peil, which is commonly used in the Netherlands to quantify height measurements.)



Legend:

{1, 3, a}	if x : x < 0.20 ∈ {1} ∧ if x : x > 0.50 ∈ {3} then {a} = active
{1, 4, a}	if x : x > 1.85 ∈ {1} ∧ if x : x > 1.25 ∈ {4} then {a} = active
{a, 1}	{a} = attribute of {1}
{a, 3}	{a} = attribute of {3}
{a, 4}	{a} = attribute of {4}
{1, I}	{1} is displayed in I
{3, I}	{3} is displayed in I
{4, I}	{4} is displayed in I
{a, c}	{a} = attribute of {c}
{c, II}	{c} is displayed in II
{1, b}	if x : x < 0.20 ∈ {1} then {b} = active if x : x > 1,85 ∈ {1} then {b} = active
{b, I}	{b} = attribute of I

Figure 4.13 Underpinning information representation of a context-dependent adaptable UI: the relevant parts of the related (a) ING, (b) CIG, (c) WIG, and (d) context-dependency graph.

In addition to managing constraining conditions, the CDG can also be used to specify how context information has to be communicated to the user. For example, if the value of a water level entity is < 0.20 N.A.P., then Window I becomes visible. All water level entities corresponding to 'water level' < 0.20 N.A.P. and vessel depth information of all vessels with depth > 0.50 meter are highlighted in Window I. And vessel icons of all vessels with a depth > 0.50 meter are highlighted in Window II. If the water level is > 1.85 N.A.P., then Window I becomes visible. All water level entities with water level > 1.85 N.A.P. are highlighted in Window I. Also, vessel depth information of all vessels with height > 1.25 meter is highlighted in Window I, and vessel icons of all vessels with a height > 1.25 meter are highlighted in Window II. The resultant CDG is shown in Figure 4.13d. To improve the readability of the graph we only visualized the type of relation between the vertices in the graph. The legend of Figure 4.13 provides an overview of the full specification for each edge.

4.6 Feasibility of the concepts

Implementation of the developed concepts is required to evaluate the usefulness of the concepts in practice. We have developed a N-ONM workplace simulator to implement a prototype of the developed concepts and to demonstrate their feasibility and applicability. The three IE-based UI concepts were applied to the UCD-based UI design presented in section 4.1. The following sub-sections present how we developed the simulator and IE-based prototypes.

4.6.1 WORKPLACE SIMULATOR DEVELOPMENT USING SCRUM

The goal of the workplace simulator was to provide a research means to test the feasibility, usability, and the effect of the UI prototypes on operators' SA, task performance, and workload. The UI developed using UCD, together with the comments made by the experts and operators after testing the detailed design 2, were used as input for the workplace simulator. Each IE-based UI prototype was composed of a set of UI features, which could be (de)activated in the simulator. The simulator was developed by employing the Scrum framework. Scrum is a framework for developing complex products, which defines to break the work that might be needed into manageable items [22]. A

Scrum Team iteratively develops a working product. In each Sprint, a time-boxed product development cycle, the development team builds those items defined by user stories which according to the Product Owner have the highest priority.

Our Scrum Team consisted of a Scrum Master, a Product Owner, and a Development Team that consisted of a system architect, a user story owner, a frontend developer, a backend developer, and a tester. The PhD candidate took the role of the Product Owner. The user story owner is a role which is not commonly part of a Scrum Development team. The user story owner in our team was responsible for user story refinement together with the Product Owner. User story refinement consisted of adding detailed information related to the user stories, which was developed in the UCD and IE steps, to the user stories. The user story owner supported the developers in building items according to what was defined in the UCD and IE steps.

A Sprint in our project had a duration of three weeks. The total product development had to take place in 11 Sprints. Re-use of existing components, databases, and the game-engine platform Unity allowed to develop a functional N-ONM workplace in this limited time. The geographic maps in the simulator were created by combining Electronic Navigational Charts (ENC's) of the Dutch waterways with ESRI shapefiles and their attributes from GeoWeb, a geographic information system used at Rijkswaterstaat. The graphical user interfaces of the information overview and information detail windows were reused from a technical pilot which took place as part of the "Vessel Traffic Management Centre of Tomorrow" project. Data from the vessel information and tracking system IVS90 was used to fill our vessel information database.

The core of the simulator software is a simulation monitor (SiMON). This component (i) executes, stops, and adapts scenarios, (ii) executes all user commands, (iii) directs the simulator, (iv) collects data from databases, the simulator, and scenarios, and (v) supports data logging. SiMON is developed as a .Net Windows service in C#. The users (i.e. test leaders, observers, and N-ONM operators) interact with the simulator software through a web interface. The web interfaces have been developed using Open Layers and Angular JS. Tomcat has been used as web server. JSON ('Rest') services have been used for communication between SiMON and the web interfaces. GeoServer has been used as server for the maps and geographic information. A simulator that determines vessel routes has been developed using Unity game engine. A schematic overview of the system components is given in Figure 4.14

A Sprint Review was held at the end of each sprint to evaluate the developed items and to discuss future work. During the Sprint Review, the Scrum Team presented the developed product to a stakeholders group. The stakeholders group consisted of six experts. Three of those experts had been involved in the UCD phase as well.

4.6.2 PROTOTYPING THE COHERENT USER INTERFACE

We used the following set theory based procedure to realize a coherent UI at redesigning the in section 4.1 developed UI:

Step 1 Based on the UI and user requirements developed through UCD, we developed a graphical user interface style guide to achieve coherency in the UI layout. The style guide defined the design of the interface elements which do not carry content information, for example, background color use and button and menu design. The total set of requirements in our style guide ensured a logical, consistent, orderly, and harmonious interface. This was achieved by specifying window layout, menu structures, navigation elements, typography, and a color palette informing about what standard colors must be used throughout the interfaces.

Step 2 We identified all UI windows of the system and defined the set of content information for each window. Set theory prescribes to use the same names to define information entities with the same meaning

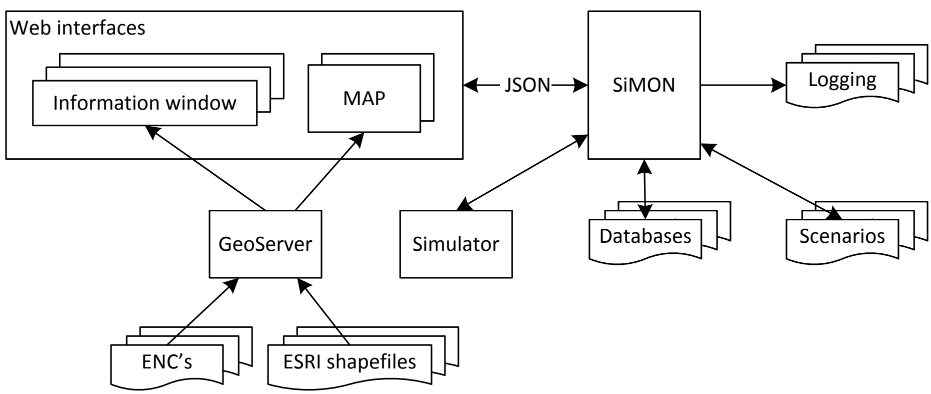


Figure 4.14 Architecture of workplace simulator software

and to check all information entities for semantic coherence. In this step we noticed that in our UCD phase there were many information entities used to describe vessel information. When analyzing all these entities, we found that different descriptions were used to describe the same information element. For example three different information elements all represented vessel type, but in different ways: “Official Vessel number (OFS) = 1510”, “Vessel number = 51”, and “Vessel type = Containership” all meant the same. We translated them all to “Vessel type”. The “Vessel identification number”, also called ENI-number in other systems, however, is not the same. Instead these contain a unique number for each vessel. Subject-matter experts (SMEs) advised to use the term ENI-number for this information element. Table 4.1 gives an overview of the windows and examples of information elements included in them. We developed information visualization and content handling rules and applied the rules to all sets to create coherency in information visualization.

Table 4.1 Prototyping the developed coherent UI for N-ONM tasks

User interface windows	Related information sets; *such as*
I. Area of Focus: Static information	A. Static information with a geographical component; *kilometer markers, anchorage grounds, lock locations*
II. Area of Focus: Dynamic vessel information	B. Dynamic vessel information with a geographical component; *vessel location, vessel direction, vessel name, vessel type*
III^{x} Information overview window (multiple tabs)	C. Information overview of all entities and their main characteristics of a certain type per tab page; *vessel overview window displaying a list of all vessels in the area of control, their destination, dimensions, etc.*
IV^{x}. Information details window (window per element listed in III^{x})	D. Details of one entity; *all relevant details on a specific vessel / event.*
V. Notification bar	E. Information about current notifications; *event title, event type, event priority level*
VI. Area of Control	F. Static information with a geographic component; *safety regions, waterway authorities, lock locations*

The rules addressed all four aspects of interface coherency as explained earlier. Examples of information visualization rules which we applied are; (i) harmonious, consistent, and logical color coding which describes the meaning of color use for all windows, (ii) logical and consistent icon design which describes which icon to use for which information entity, (iii) consistent use of unit of measure, which determines which unit to use, e.g. we used kilometer and not miles, Celsius and not Fahrenheit.

Step 3 We identified intersection of the content information sets, see Figure 4.15. All UI windows with a geographic component (I, II and VI) share the same electronic navigational chart vector data; $A \cap B \cap F$ = {water, land, waterway}. The information layers in window VI are also presented in window I; $F \subseteq A$ = {safety regions, waterway authorities, lock locations}. Some information entities presented in window II are also present in window III^1 and IV^1; $B \cap C^1 \cap D^1$ = {vessel name, vessel length, vessel width, vessel height, vessel type, number of blue cones}. They, however, had different data sources. These data sources also had a different update frequency, which in the current system can result in conflicting information. The information entities presented in window V are also presented in window III^2; $E \subseteq C^2$ = {notification type, notification name, notification priority level}. All information presented in window III is also presented in window IV; $C \subseteq D$.

Step 4 We defined rules to handle intersection of sets and applied them to all intersecting sets. To deal with inconsistency due to different data sources, we specified that the system keeps the value which is changed most recently and thus overrides the content of all information sets in which the changed entity is present; (i) user input overrides data stored in source x, (ii) in case of conflict between two sources, the most recent entry prevails.

The resultant UI design was implemented in the N-ONM workplace simulator by Feature 1: Coherency between all UI windows (same map view, consistent information content, same use of color, same way of operation). Screenshots of the developed UI are given in Figure 4.16 and Appendix VIII.

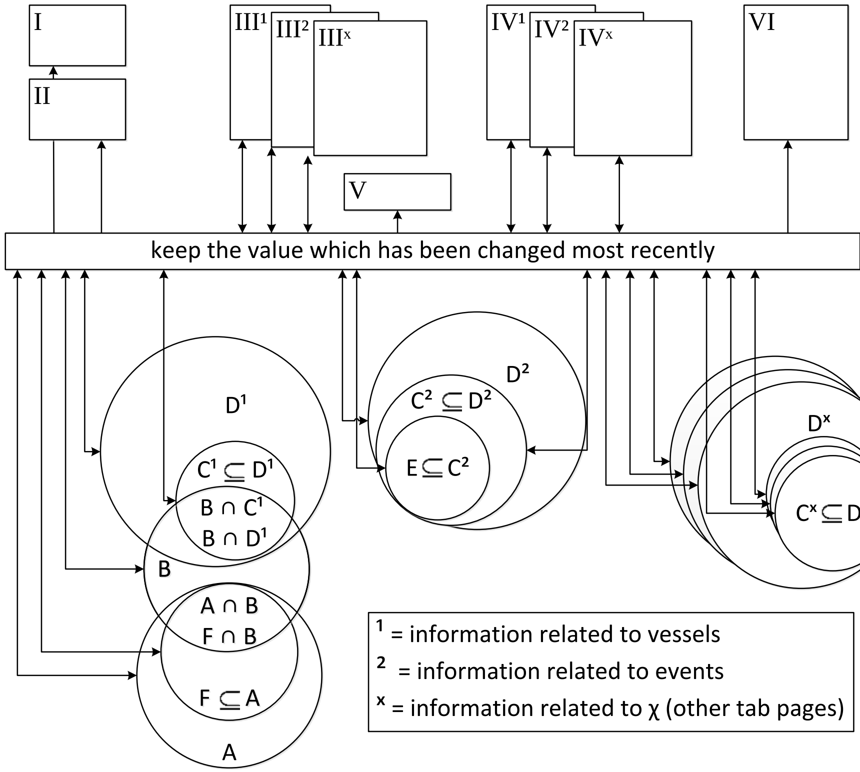


Figure 4.15 Coherent user interface specification based on set theory (the circles represent the information sets)

4.6.3 PROTOTYPING THE INTEGRATED USER INTERFACE

We used the following set theory and common graph theory based procedure to design an integrated UI for N-ONM tasks:

Step 1 In the UCD phase, we identified five N-ONM tasks, which are presented together with the related sub-tasks in Table 4.2. The table includes 24 of the total set of information entities, which are required for these five tasks. We applied the same naming to information entities having the same meaning.

Step 2 The tasks identified in the task analysis and their corresponding information subsets were represented as vertices of the ING, see Figure 4.17. We used Greek symbols for identification of tasks and uppercase letters for identification of information sets: the union of sets, U = A ∪ B ∪ C ∪ D ∪ E.

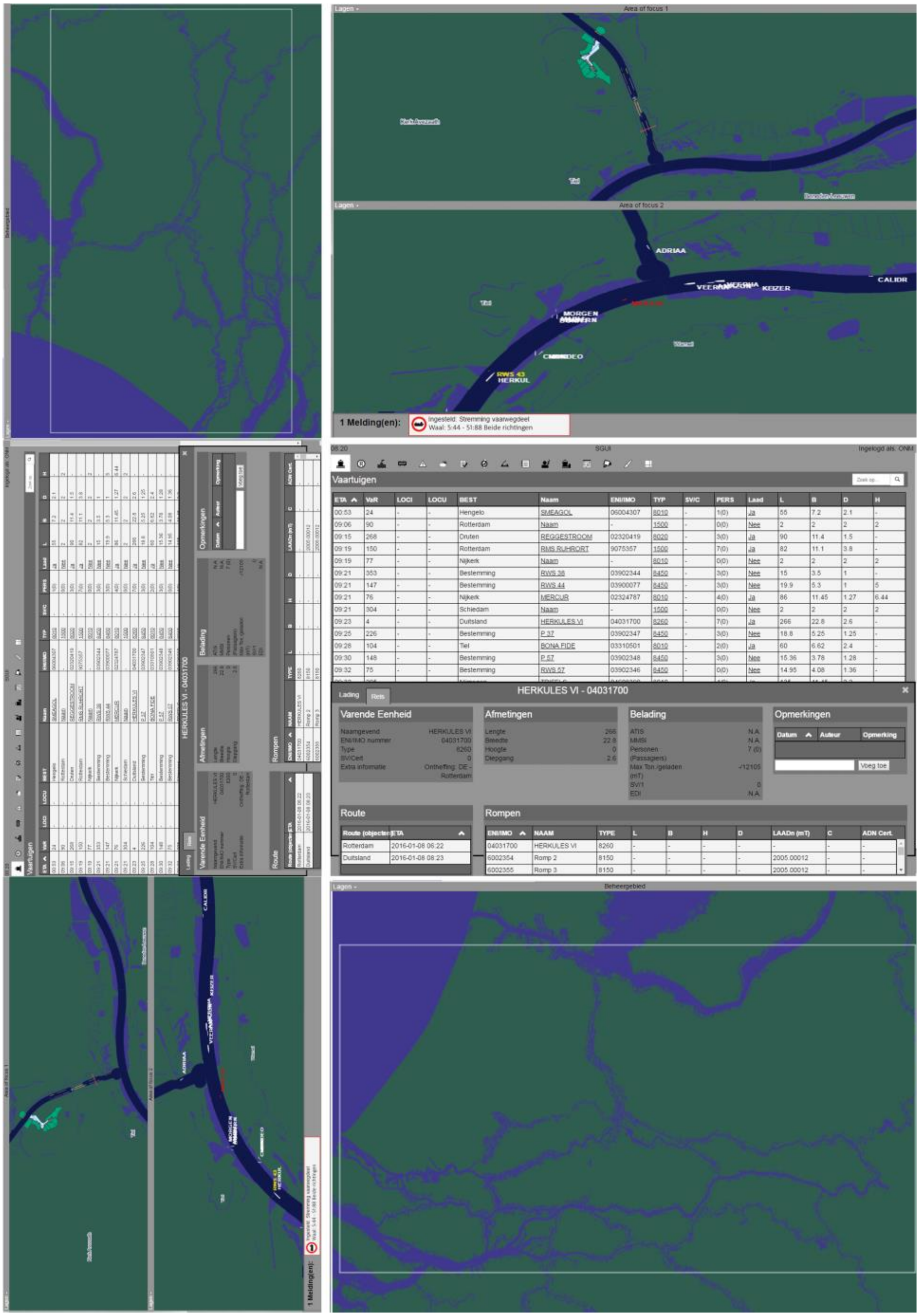


Figure 4.16 Screenshot of the implemented coherent user interface. Left: overview of the three screens. Right: screenshot per screen.

Table 4.2 N-ONM tasks and examples of information entities per task

Tasks	Information entities
α = Assess traffic conditions α^1: locate / identify shipping α^2: Follow shipping α^3: Observe network α^4: Register information	{A} = 1. Waterway, 2. Vessel ID, 3. Vessel location, 4. Vessel type, 5. Vessel direction, 6. Vessel speed, 7. Vessel destination, 8. Anchorage ground location, 9. Anchorage ground usage, 10. Event type, 11. Event location, 12. Traffic measure type, 13. Traffic measure location, 14. Log type, 15. Log content , 16. Event start time, 23 Current time.
β = Inform stakeholders β^1: provide traffic information β^2: provide information in case of restrictions	{B} = 1. Waterway, 2. Vessel ID, 3. Vessel location, 4. Vessel type, 8. Anchorage ground location, 9. Anchorage ground usage, 10. Event type, 11. Event location, 12. Traffic measure type, 13. Traffic measure location, 16. Event start time, 17. Event end time, 18. Traffic measure start time, 19. Traffic measure end time, 20. Vessel cargo, 21. Safety regions, 22. Waterway authority, 23. Current time.
γ = Manage incidents	{C} = 2. Vessel ID, 3. Vessel location, 4. Vessel type, 10. Event type, 11., Event location, 12. Traffic measure type, 13. Traffic measure location, 20. Vessel cargo
δ = Plan traffic measures δ^1: Determine impact of restrictions δ^2: Prepare traffic measures	{D} = 1. Waterway, 10. Event type, 11., Event location, 12. Traffic measure type, 13. Traffic measure location, 16. Event start time, 17. Event end time, 18. Traffic measure start time, 19. Traffic measure end time, 21. Safety regions, 22. Waterway authority, 24. Lock location
ε = Set / release traffic measures ε^1: Set traffic measures ε^2: Lift traffic measures ε^3: Register information	{E} = 1. Waterway, 12. Traffic measure type, 13. Traffic measure location, 14. Log type, 15. Log content , 18. Traffic measure start time, 19. Traffic measure end time. 23. Current time

The information entities were specified as a third type of vertices, which we represented using numbers. Each information entity which

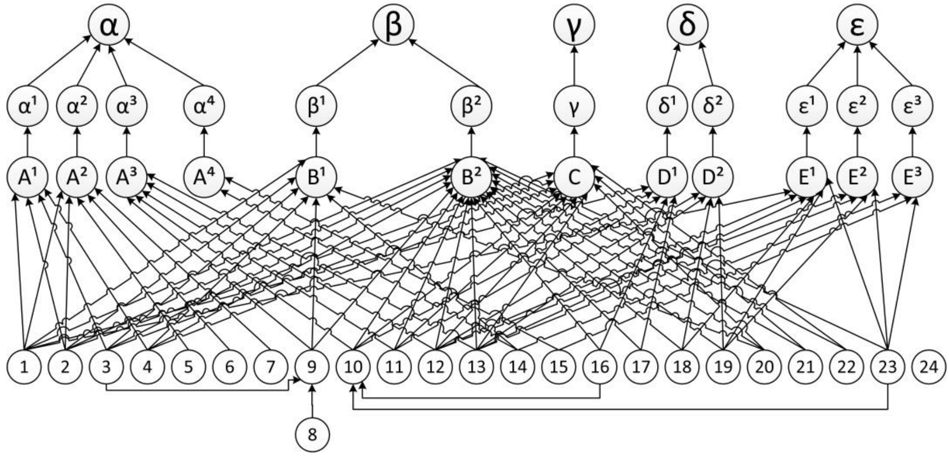
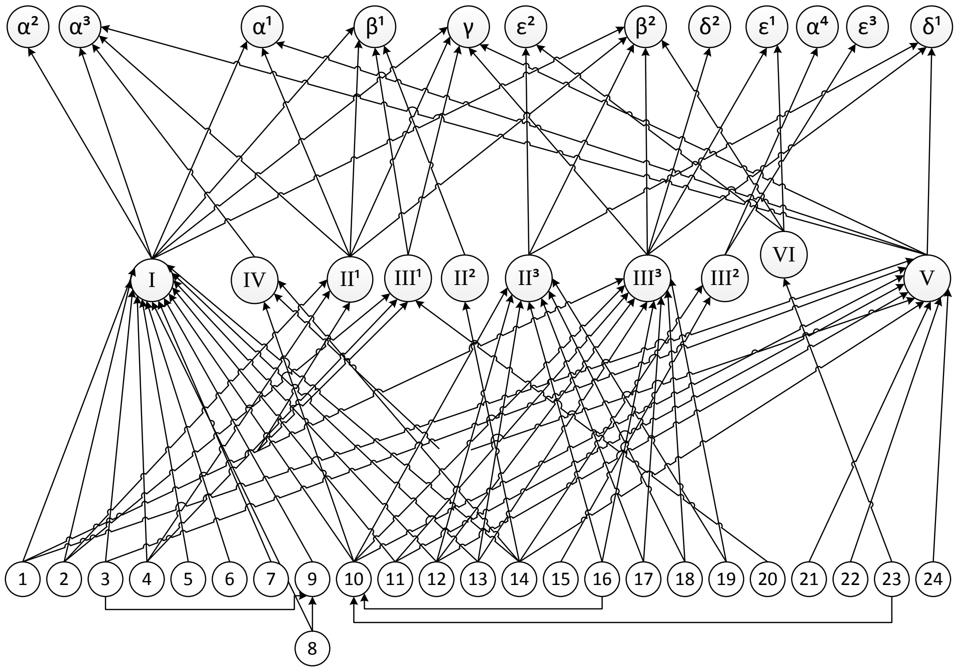


Figure 4.17 Information needs graph (ING) of the developed integrated user interface for N-ONM tasks

was part of U was represented by its own vertex. Edges between the vertices were defined to specify which information entity is needed for which task. The information entity {9} 'Anchorage ground usage' was assessed by comparing {8} 'Anchorage ground location' with {3} 'Vessel location'. If there is an overlap between $X_1\{3\}$ and $X_1\{8\}$, then $X_1\{9\}$ is in use. Else $X_1\{9\}$ is not in use. This is represented by edges pointing from {3} and {8} towards {9}. The information entities {16} 'Event start time' and {23} 'Current time' are used to decide whether planned events are already active, which is stored as status in {10} 'Event type'.

Step 3 Paths were identified in the ING to establish logical groups of sets. This step revealed that multiple tasks require the same geographic information, which best could be visualized in one map. Planning traffic measures, however, requires geographic information of a different type and scale. This information therefore is best visualized in a separate map. The subset of 24 information entities, used as example in this chapter, was arranged in 10 logical groups. These logical groups of sets and related design decisions were included in a CIG which defines which information entities are presented in which UI window, see Figure 4.18. Compared with the coherent UI presented in sub-section 4.6.2, the integrated UI had the same types of UI windows, except that the different Area of Focus windows were integrated and the information subset ‘Current time’ was placed in its own window.



Supported tasks per window	Information entities per window
I = Area of Focus map: $\alpha^1, \alpha^2, \alpha^3, \beta^1, \beta^2, \gamma$	I = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14}
II^1 = Vessel overview window: $\alpha^1, \alpha^3, \beta^1, \beta^2, \gamma$	II^1 = {2, 4, 7}}
II^2 = Log overview window: β^1	II^2 = {14}
II^3 = Event / traffic measures overview window: $\beta^2, \delta^1, \varepsilon^2$	II^3 = {10, 12, 13, 16, 17, 18, 19}
III^1 = Vessel detail window: β^1, γ	III^1 = {2, 4, 7, 20}
III^2 = Log detail window: α^4, ε^3	III^2 = {14, 15}
III^3 = Event / traffic measures detail window: $\beta^2, \gamma, \delta^1, \delta^2, \varepsilon^1$	III^3 = {1, 10, 11, 12, 13, 16, 17, 18, 19}
IV = Notification bar: α^3	IV = {10, 12, 14}
V = Area of Control map: $\alpha^1, \alpha^3, \beta^2, \gamma, \delta^1$	V = {1, 3, 10, 11, 12, 13, 14, 21, 22, 24}
VI = Time panel: $\beta^2, \varepsilon^1, \varepsilon^2$	VI = {23}

Figure 4.18 Content integration graph (CIG) of the developed integrated user interface for N-ONM tasks

Step 4 The same graphical user interface style guide was applied to all windows of the integrated UI as which was used for our coherent UI.

Step 5 Paths were identified in the ING and CIG to define which windows to display as adjacent windows. Several N-ONM tasks required information from multiple UI windows. Timing of tasks was carefully considered. The most time consuming task of a N-ONM operator is task α^3 ‘Observe Network’. The most critical N-ONM tasks is γ ‘Manage incidents’. Completing this task puts high demands on N-ONM operators in terms of required response times and this task has a low allowed error tolerance. The windows I, II and IV supporting task α^3, needed to be displayed as adjacent windows in the system’s UI. The windows I, II and III, which support task γ, needed to be adjacent as well. The UI developed through UCD was not in line with this insight, as the detail information window was not located next to the area of focus window, see Figure 4.5. The design shown by the screenshots of the UI in Figure 4.19 and Appendix VIII allowed providing sufficient support of both tasks.

Step 6 Paths were identified in the CIG to determine shared information entities and tasks. We displayed these shared vertices as weighted edges in a WRN, see Figure 4.20. Windows in the CIG are related if they support the same task(s) or if they display the same information entity or entities.

Step 7 We evaluated all edges in the WRN to identify useful interactions between windows. The evaluation pointed at the fact that several windows which support the same task do not share information entities. For most of these edges our conclusion was that there is no useful interaction between the represented windows. An exception is the interaction between the windows II^1 and V. These windows do not share information entities either, but we identified a useful interaction between them. Window II^1 shows vessel names. Window V displays the location of a vessel by showing a marker on the map. For the shared task γ “Manage incidents” we found it useful to quickly find the location of a vessel. We supported this by highlighting the location of a vessel in V when clicking this vessel’s name in II^1. The identified useful interactions are presented in the WIG in Figure 4.21.

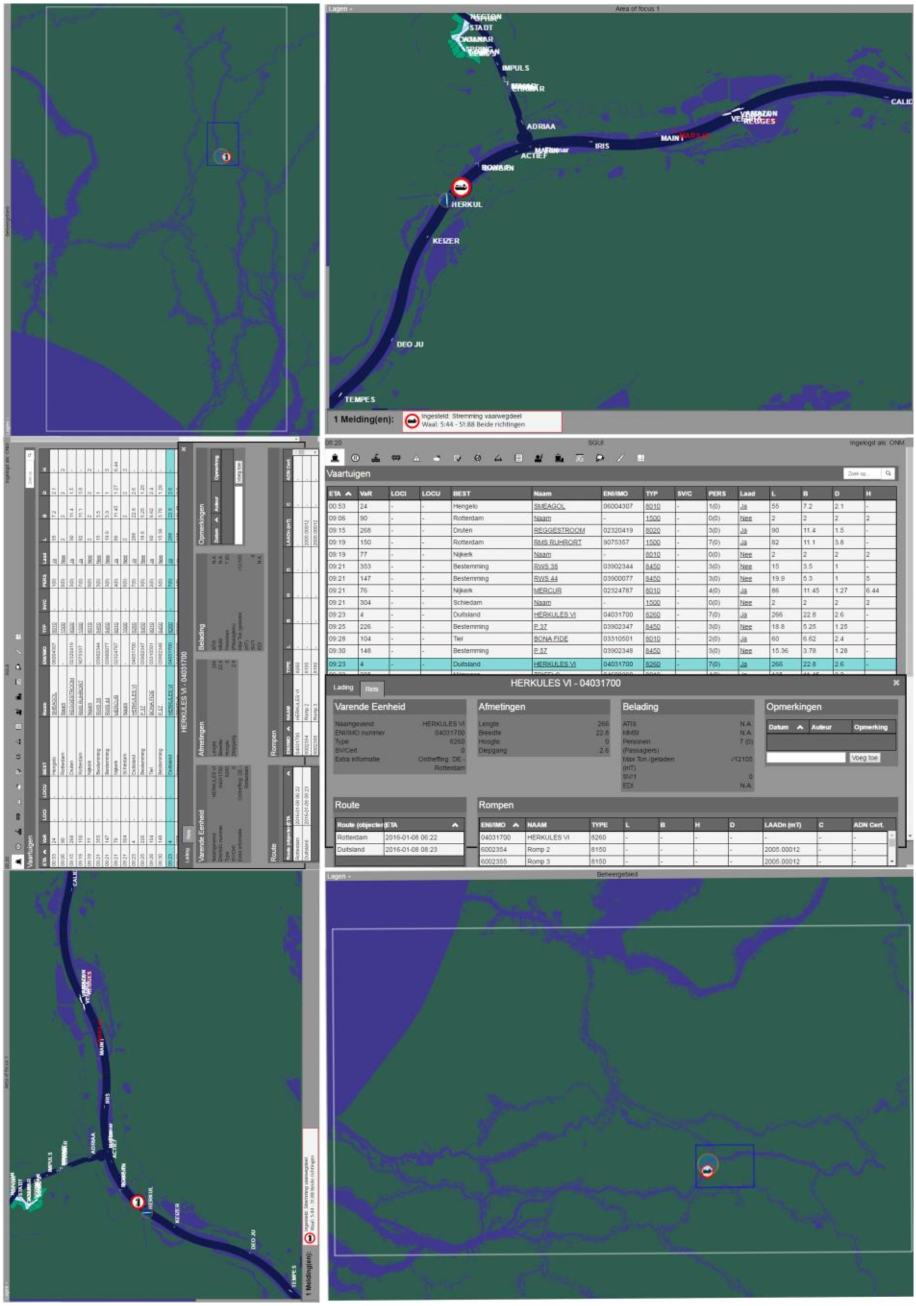


Figure 4.19 Screenshot of the implemented integrated user interface. Left: overview of all three screens. Right: screenshot per screen.

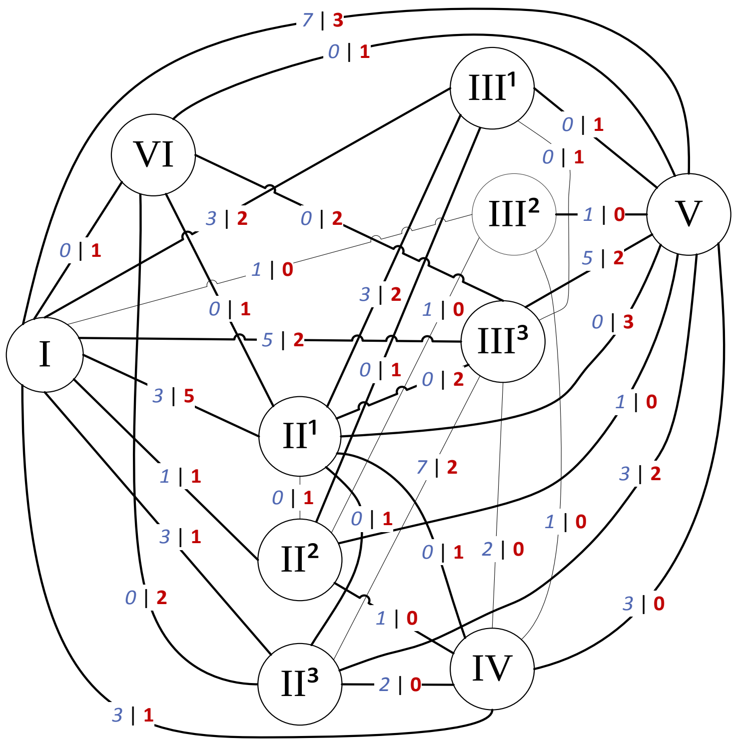


Figure 4.20 Window relations network (WRN) of the developed integrated user interface for N-ONM tasks. *Italic blue* = amount of shared tasks. **Bold red** = amount of shared information entities between windows.

The resultant UI design was implemented in the N-ONM workplace simulator by Feature 1 - 6:

Feature 1: Coherency between all UI windows (same map view, consistent information content, same use of color, same way of operation)

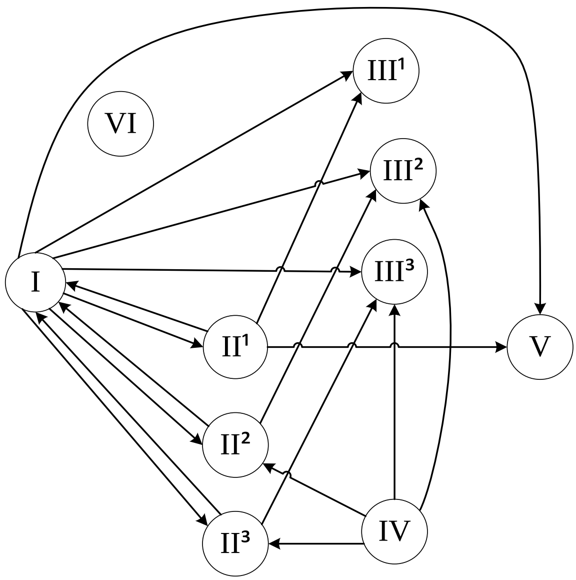
Feature 2: All geographic information integrated on the same map

Feature 3: Highlight location of object on the map by clicking on this object in the information overview window

Feature 4: Open detail window of object by clicking this object on the map

Feature 5: Filter vessel overview window based on the estimated time of arrival of the vessels at a particular location

Feature 6: View type, status, and location of events / notifications on a map



{I, II^1}	Click vessel in I to open II^1. Click vessel in I to highlight this vessel in II^1. Click vessel in II^1 to highlight this vessel in I
{I, II^2}	Click log in I to open II^2. Click log in I to highlight this log in II^2. Click log in II^2 to highlight this log in I
{I, II^3}	Click event / traffic measure in I to open II^3. Click event / traffic measure in I to highlight this event / traffic measure in II^3. Click event in II^3 to highlight this event / traffic measure in I.
{I, III^1}	Double click vessel in I to open III^1 of this vessel.
{I, III^2}	Double click log in I to open III^2 of this log
{I, III^3}	Double click event / traffic measure in I to open III^3 of this event / traffic measure
{I, V}	Click vessel in I to highlight the location of this vessel in V The area displayed in I is visualized as a red rectangle in V
{II^1, III^1}	Double click vessel in II^1 to open III^1 of this vessel
{II^1, V}	Click vessel in II^1 to highlight the location of this vessel in V
{II^2, III^2}	Double click log in II^2 to open III^2 of this log
{II^3, III^3}	Double click event / traffic measure in II^3 to open III^3 of this event / traffic measure
{IV, II^2}	Click notification about log in IV to open II^2 of this log
{IV, III^2}	Double click notification about log in IV to open III^2 of this log
{IV, II^3}	Click notification about event / traffic measure in IV to open II^2 of this event / traffic measure
{IV, III^3}	Double click notification of event / traffic measure in IV to open III^2 of this event / traffic measure

Figure 4.21 Windows interaction graph (WIG) of the developed integrated user interface for N-ONM tasks with defined interaction per edge in text.

4.6.4 PROTOTYPING THE CONTEXT-DEPENDENT ADAPTABLE USER INTERFACE

When designing a context-dependent adaptable UI for N-ONM tasks, we used the following semantic network based procedure:

Step 1 We used the results of the steps 1 – 7 discussed in Section 4.6.3 as a starting point for the development of a context-dependent adaptable UI.

Step 2 The information acquired through task analyses and insights from four SME were used to identify relevant contextual conditions. Relevant conditions are conditions that influence required SA for N-ONM tasks. The use of set theory and SNW helped to specify these conditions and to relate them to the information elements and UI windows. The identified conditions are all related to task α^3 'Observe network'.

Condition 1: If there is an active and/or planned event; $\{10\} \neq \emptyset$.

Condition 2: If there is an currently active obstruction on the main route; $x : x_i = c \in \{10\} \wedge 11\{x_i\} \cap \{25\} \wedge 16\{x_i\} \leq \{23\}$. In this symbolic constraint statement, $\{25\}$ = set of coordinates representing the main route.

Condition 3: If the traffic density somewhere in the area of control is equal to or larger than a threshold; $x : x \geq 10 \in \{33\}$. In this statement, $\{33\}$ is the set of current traffic density levels and $33\{\chi\} = 2*n(pt \in 32(GID\chi)) + 0.1*n(rv \in 32\{GID\chi\}) + 0,1*n(pv \in 32\{GID\chi\}) + 1*n(ot \in 32\{GID\chi\})$.

The definitions of the prescriptive context information entities required to define these conditions are given in Table 4.3. Specifying conditions required to create new (subsets of) information elements, i.e. {25} – {33}. These information elements were not identified earlier, because they so far were only part of operators mental image of the environment. Building a context-dependent adaptable UI requires to implement these information elements in the system as well.

Table 4.3 Overview of information entities required to specify information content per condition for N-ONM tasks (continues on next page)

Information entities	Definitions
{10} Event type	Set of events given by (type, status). Possible types are (a) obstruction complete lock, (b) obstruction partial lock, (c) obstruction waterway, (d) hindrance waterway, and (e) information event. Possible states are (0) planned and (1) active.
{11} Event location	Set of (latitude, longitude) coordinates of events
{16} Event start time	Set of start times of events in yy.mm.dd.hh.mm.ss
{23} Current time	Set of current time in yy.mm.dd.hh.mm.ss
{25} Main route	Set of (latitude, longitude) coordinates of main route
{26} Availability main route	Set of availability of main route. Possible objects are: (available) and (not available)
{27} Alternative route A	Set of (latitude, longitude) coordinates of alternative route A
{28} Availability alternative route A	Set of availability of alternative route A. Possible objects are: (available) and (not available)
{29} Alternative route B	Set of (latitude, longitude) coordinates of alternative route B
{30} Availability alternative route B	Set of availability of alternative route B. Possible objects: (available) and (not available)
{31} Area of control grid	Set of (GID, X(latitude, longitude), Y(latitude, longitude) coordinates of the area of control. In which GID = grid identification number, X = top left corner of GID, and Y is bottom right corner of GID. E.g. {31} can be (1, (51.72, 5.96), (51.68, 6.03)). $\cup$ = area of control.
{2} Vessel ID	Set of all European Number of Identification (ENI) numbers of vessels in the area of control. ENI is a unique reference for ships.
{3} Vessel location	Set of (latitude, longitude) coordinates of all vessels in the area of control. {3} is related to {2} such that each object of {3} is given by (ENI, (latitude, longitude)).

Table 4.3 (Continuation from previous page) Overview of information entities required to specify information content per condition for N-ONM tasks

Information entities	Definitions
{4} Vessel type	Set of vessel type for all vessels in the area of control. Possible types are: (pt) push towing, (rv) recreational vessel, (pv) patrol vessel, and (ot) other. {4} is related to {2} such that each object of {4} is given by (ENI, type). For example (9628192, ot).
{32} Vessels in grid	Set of which vessels are in which 5 square km of the area of control. Set {32} is related to {31}, {2}, {3} and {4} such that each object of {32} is given by (GID, ENI, (latitude, longitude) type).
{33} Current traffic density	Set of current traffic density levels. {33} is related to {31} such that {33} = {(GID, density)}. Object attribute 'density' is calculated using set {32}. All objects in set {32} with the same GID(χ) are used to calculate 'density' for this GID. 33{χ} = 2*n(pt ⊆ 32(GIDχ)) + 0.1*n(rv ⊆ 32{GIDχ)) + 0,1*n(pv ⊆ 32{GIDχ)) + 1*n(ot ⊆ 32{GIDχ))

Step 3 For each identified contextual condition we redesigned the UI to support operators to gain and maintain SA required under these circumstances. The SNW shows which information entities and windows are relevant under which conditions. This insight helped designers to specify which information to display how, where, and when. In case of Condition 1 it is relevant to present an extra Area of Focus window displaying the event location; I^2. In case of Condition 2 it is relevant to visualize the available alternative routes and the obstructed main route in Window V. In case of Condition 3 it is relevant to display traffic density information in Window V.

Step 4 We updated the CIG obtained in step 1 with the information entities required to define the relevant context conditions, see Table 4.3, and added a vertex for Window I^2, see Figure 4.22. I^2 displays the same information entities as I^1 and has the same interaction with the other windows as I^1. The updated WIG together with de specification of the interaction between I^2 and the other windows is given in Figure 4.23.

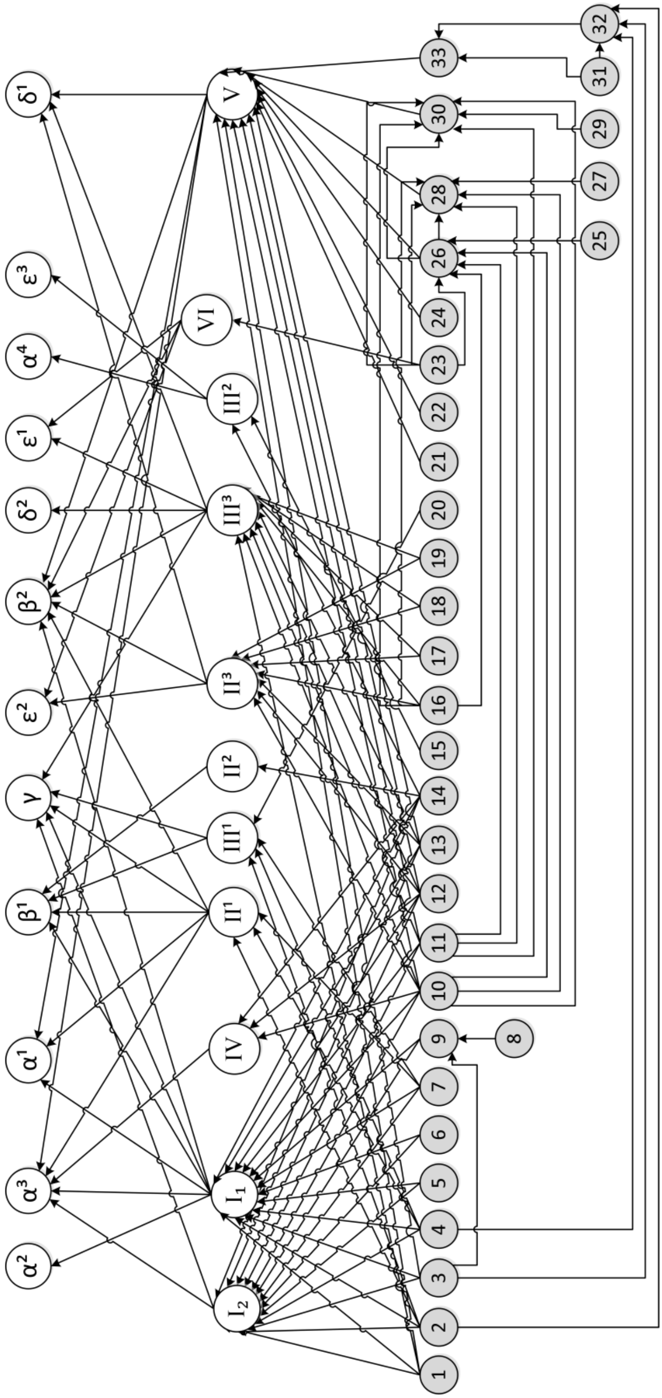
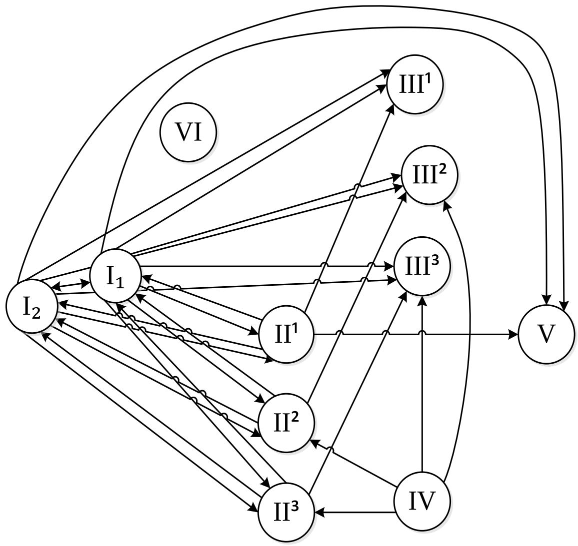


Figure 4.22 Content integration graph of the context-dependent adaptable user interface for N-ONM tasks



{I_1, I_2}	Click element in I_1 to highlight this element in I_2 Click element in I_2 to highlight this element in I_1
{I_2, II^1}	Click vessel in I_2 to open II^1 Click vessel in I_2 to highlight this vessel in II^1 Click vessel in II^1 to highlight this vessel in I_2
{I_2, II^2}	Click log in I_2 to open II^2 Click log in I_2 to highlight this log in II^2 Click log in II^2 to highlight this log in I_2
{I_2, II^3}	Click event / traffic measure in I_2 to open II^3 Click event / traffic measure in I_2 to highlight this event / traffic measure in II^3 Click vessel in II^3 to highlight this event / traffic measure in I_2
{I_2, III^1}	Double click vessel in I_2 to open III^1 of this vessel
{I_2, III^2}	Double click log in I_2 to open III^2 of this log
{I_2, III^3}	Double click event / traffic measure in I_2 to open III^3 of this event / traffic measure
{I_2, V}	Click vessel in I_2 to highlight the location of this vessel in V The area displayed in I_2 is visualized as a blue rectangle in V

Figure 4.23 Window interaction graph of a context-dependent adaptable user interface for N-ONM tasks

Step 5 Interface composition entities were defined to describe the total of semantic relations between information entities and adaptable UI elements, which played a role in a particular condition, see Table 4.4.

Step 6 We mapped both the context conditions, the context information entities, and the interface composition entities in a CDG, see Figure 4.24.

a. We defined the following paths in the CDG to specify Condition 1:
   - if {10} ≠ ∅, then {α} = visible, else {α} = not visible. {α} = attribute of {I_2}
   - if x : x_i = a ∈ {10} ∨ x : x_i c ∈ {10}, then 11{x_i} = coordinates (latitude, longitude) is center of map displayed in I_2; if |10| with x : x_i = a ∈ {10} ∨ x : x_i c ∈ {10} > 1, then center of map displayed in I_2 = {11} of event with lowest |23{x_i} – 16{x_i}|.
   - Else if x : x_i = b ∈ {10} ∨ x : x_i = d ∈ {10} then 11{x_i} = coordinates (latitude, longitude) is center of map displayed in I_2; if |10| with x : x_i = b ∈ {10} ∨ x : x_i = d ∈ {10} > 1 then center of map displayed in I_2 = {11} of event with lowest |23{x_i} – 16{x_i}|
   - Else if x : x_i = e ∈ {10} then 11{x_i} = coordinates (latitude, longitude) is center of map displayed in I_2; if |10| with x : x_i = e ∈ {10} > 1 then center of map displayed in I_2 = {11} of event with lowest |23{x_i} – 16{x_i}|.

In prose these paths mean that if there is a planned or active event, then the extra area of focus is visible. The coordinates of the center of the map visualized in this window are the coordinates of the event. If there are

Table 4.4 Interface composition entities and their possible values

Interface composition entity	Possible values
{α}= status of I_2	Visible | Not visible
{β} = color in which {26} is displayed in V	#11194C | #6E87C8
{γ} = color in which {28} is displayed in V	#11194C | #A046A0
{δ} = color in which {30} is displayed in V	#11194C | #A046A0
{ε} = status of {33}	Visible | Not visible
{ζ} = color in which {33} is displayed in V	#11194C | #8ADD50 | #F7DB14 | #E61414
{Δ} = center of map I_2	11: {latitude, longitude} of event with lowest difference between {23} and {16}

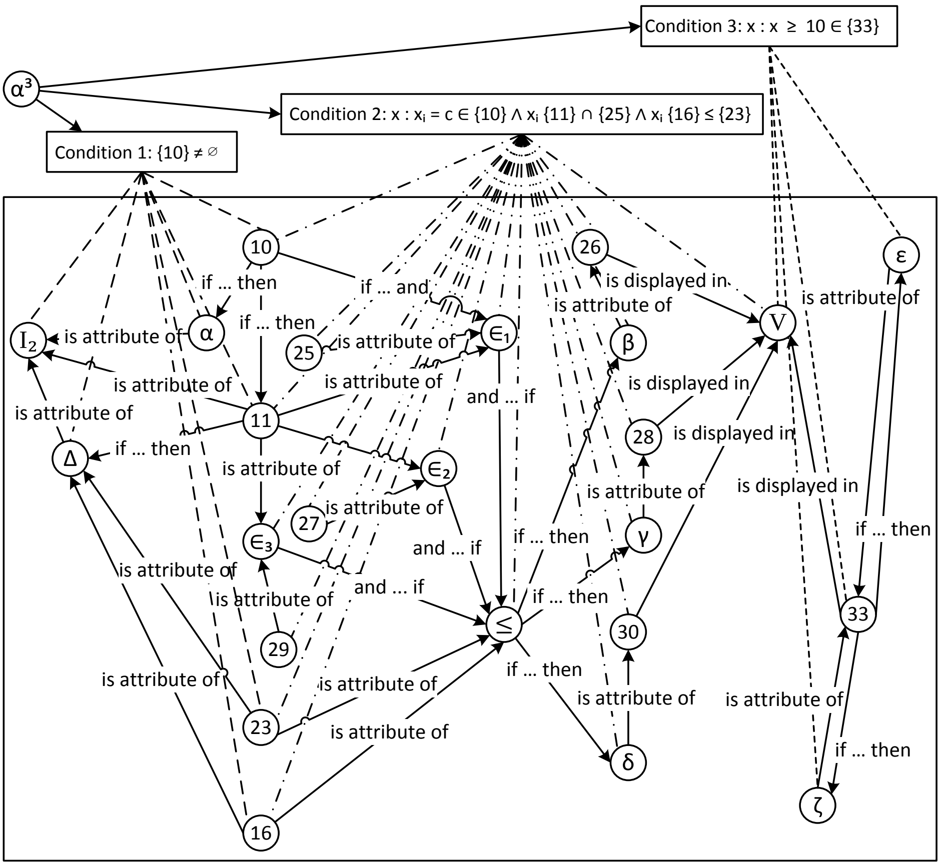


Figure 4.24 Context-dependency graph of a context-dependent adaptable user interface for N-ONM tasks

multiple events, then the event type and event start time determine which coordinates are taken as the center of the map.

b. We defined the following paths in the CDG to specify Condition 2:
   - if x : x_i = c ∈ {10} ∧ 11{x_i} ∩ {25} ∧ 16{x_i} ≤ {23}, then {β} = #6E87C8 (grey blue), else {β} = #11194C (water). {β} = attribute of {26}. {26} is displayed in V.
   - if x : x_i = c ∈ {10} ∧ 11{x_i} ∩ {25} ∧ 16{x_i} ≤ {23}, then if x : x_i = a ∈ {10} ∨ x : x_i = c ∈ {10} ∧ 11{x_i} ∩ {27} ∧ 16{x_i} ≤ {23} then {γ} = #11194C (water), else {γ} = #A046A0 (violet). {γ} = attribute of {28}. {28} is displayed in V.
   - if x : x_i = c ∈ {10} ∧ 11{x_i} ∩ {25} ∧ 16{x_i} ≤ {23}, then if x : x_i = a ∈ {10} ∨ x : x_i = c ∈ {10} ∧ 11{x_i} ∩ {29} ∧ 16{x_i} ≤ {23}, then {δ} =

#11194C (water), else {δ} = #A046A0 (violet). {δ} = attribute of {30}. {30} is displayed in V.

In prose these paths mean that if there is an obstruction on the main route, then the main route is visualized in grey blue and if at that moment there is no obstruction on an alternative route, then this alternative route is visualized in violet. Else the routes are visualized in the color blue used to visualize water.

c. We defined the following paths in the CDG to specify Condition 3:
   - if $x : x \geq 10 \in \{33\}$, then {ε} = visible, else {ε} = not visible. {ε} = attribute of {33}
   - if $33\{x_i\} \leq 5$, then {ζ} = #11194C (water)
   - if $33\{x_i\} > 5 \land 33\{x_i\} \geq 10$, then {ζ} = #8ADD50 (green)
   - if $33\{x_i\} > 10 \land 33\{x_i\} \geq 15$, then {ζ} = #F7DB14 (yellow)
   - if $33\{x_i\} > 15$, then {ζ} = #E61414 (red)
   - {ζ} = attribute of {33}. {33} is displayed in V.

In prose these paths mean that if the calculated traffic density is larger than 10, then traffic density is visualized in window V. The color of a part of the waterway corresponds to the traffic density on that part of the waterway.

The following features were implemented to generate the resultant UI design:

Feature 1: Coherency between all UI windows (same map view, consistent information content, same use of color, same way of operation)

Feature 2: All geographic information integrated on the same map

Feature 3: Highlight location of object on the map by clicking on this object in the information overview window

Feature 4: Open detail window of object by clicking on this object on the map

Feature 5: Filter vessel overview window based on the estimated time of arrival of the vessels at a particular location

Feature 6: View type, status, and location of events / notifications on a map

Feature 7: Context-dependently display a relevant location in a second area of focus window

Feature 8: Context-dependently display prognoses information in area of control map

Feature 9: Context-dependently display available alternative routes in area of control map if the main route is not available

Screenshots of the UI are given in Figure 4.25 and Appendix VIII.

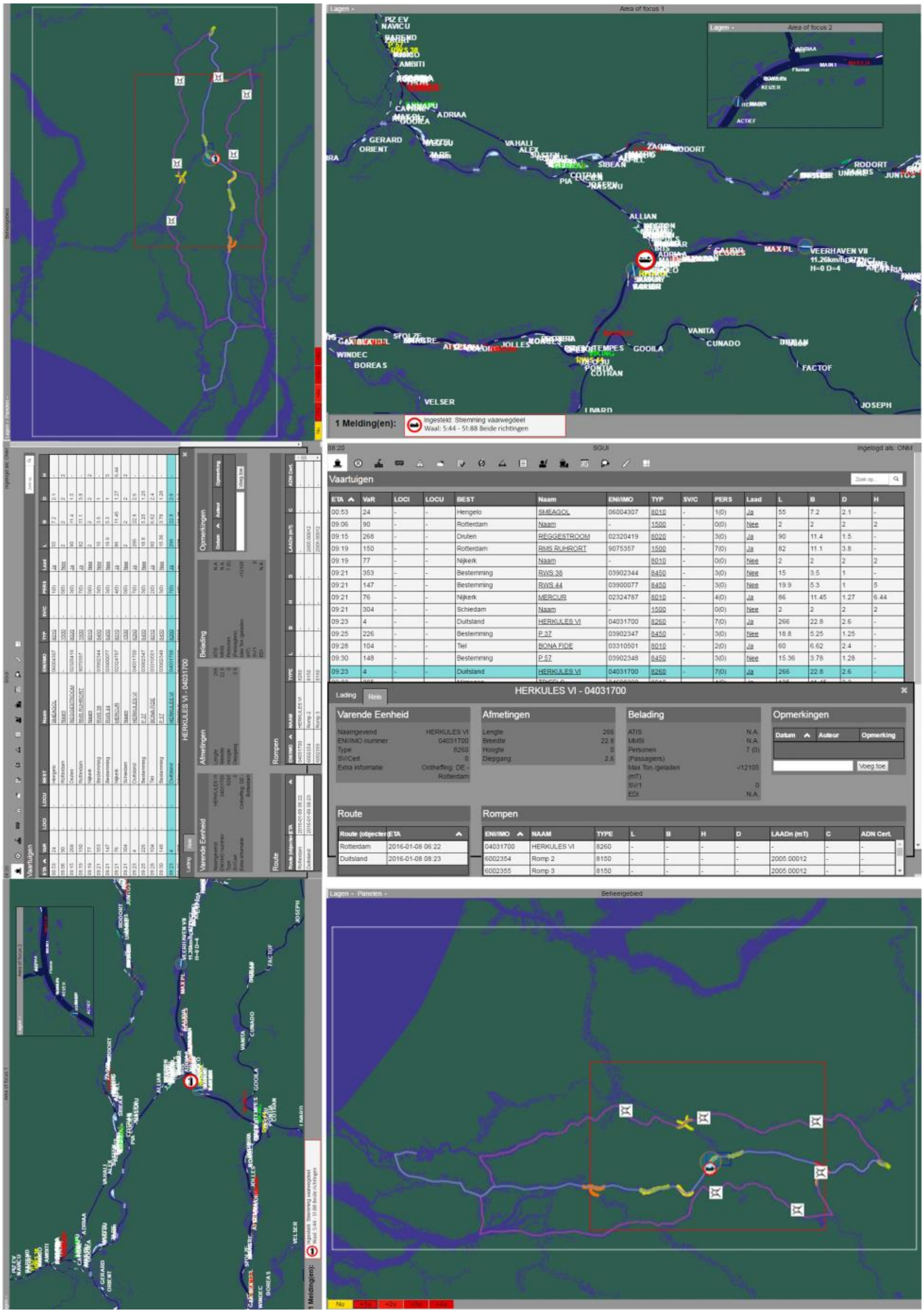


Figure 4.25 Screenshot of the implemented context-dependent adaptable user interface with all conditions active. Left: overview of all three screens. Right: screenshot per screen.

4.6 Discussion

The motivation of our research has been to overcome deficiencies of supporting SA of current system interfaces. Other studies presented in UI literature which aim to improve UI design commonly start with identification of novel technological affordance or powerful design concepts. This is usually followed by studies to explore their effects on the operator's SA in a specific application context. Examples of these approaches are ecological interface designs for nuclear process control [23] [24], integrated user interface designs for nurses in intensive care units [25], and interface designs for supporting the situation awareness of anesthesiologists [26]. In this chapter, we have discussed how we instead complemented UCD with the insights concerning the deficiencies of current systems and formal modeling methods used for IE as a robust basis of formulating concepts of efficient UIs.

We have used a set theory-based approach to map information entities to the UI windows and to formalize information handling by the interfaces. Although different formal modeling techniques can also be used to specify UI, set theory is well-accepted as a robust basis for computational modeling of interfaces. For example, Duke at al. [27] have shown that formal specification techniques based on set theory can clarify what information can or should be presented to users and to specify the effect user actions should have. Bowen and Reeves [8] have proposed to formalize the meaning of UCD outcomes in a presentation model based on set theory. This approach ensures correct and robust implementation of design guidelines describing UI properties or design rules, such as rules for consistency.

The results shown in this chapter provide evidence that set theory can be used more widely than just to specify UI design. Additionally, we have used set theory to support designers in their analysis and concept development. In our case study, application of set theory helped to identify that the different maps used in current systems use different data sources for displaying vessel information than the information overview and information detail windows. This insight helped to design information handling rules to support information consistency. We also came across different information elements which all represented the same information. Input from SMEs was needed to identify which data needed to be considered the same and which needed to be considered as separate information elements. After that, the same data and terminology could be used throughout the whole system. By making the overlaps explicit, set theory has helped in preventing conflicting information and in preventing confusing information due to different ways of representing similar or the same data. To conclude, our case study showed that formal modeling helped to improve the coherency of the UI designed through UCD.

This chapter has shown that directed graphs can be used to support designing integrated UIs. As a matter of fact, using directed graphs to represent the relationships between various information entities/sets of UIs has some preliminaries in the literature. For example, Lumertz et al. [9] have focused on modeling UI components (e.g. tabs, forms, lists) to keep consistency between their visual and behavioral characteristics. They have shown that graph representation of UI contents helps to maintain consistency between the interface windows of a system. They, however, did not discuss how formal modeling can support information content handling. Baumgartner et al. [28] also have used directed graphs to model relations between information entities. But in contrast to our approach, they have focused on spatial and temporal relations between information entities. We have focused on operator’s tasks. While their proposed approach is useful to design information fusion, it does not support designing content interaction of multiple user interface windows.

In our case study, the use of graph theory in IE helped to identify relations among information elements. The graphs revealed that two of the maps showed highly related data. For multiple tasks, the operators used both maps simultaneously. This insight helped designers to avoid or reduce displaying disjoint information elements. We integrated the information elements in a single map. The use of graph theory also pointed towards locations for meaningful interactions between different UI windows. In our case, we found multiple relations between the information overview and information detail windows and the Area of Focus map. We therefore considered it logical to make these relations explicit in the UI design. Compared to the UI developed through UCD, this resulted in changing the place of the information detail window and in several interactions between the windows. Graph theory, however, did not help in designing the content of these interactions. For this we relied on the expertise of the designers.

To model the information constructs for context-dependent adaptable UI, we have used a semantic network approach. As an extension of common graphs, a semantic network can represent not only connectivity, but also the semantic nature of the relationships between information constructs. This can be visualized as multi-layer space-graphs. Resembling our approach, Sottet et al. have used graph representation as the basis of a task model, a concept model, and a model of the context of use [11]. The edges between the information entities were used by them to denote mathematical rules such as context conditions.

Likewise, the computational framework proposed by Motti and Vanderdonckt for a context-aware adaptable UI was based on graph representation to establishing mappings between context information and UI adaptation rules [10]. Their framework has focused on adaptation of UIs to fit different platforms and devices. As such it is suitable to specify the UI adaptations, but does not support context-dependent information handling. Similarly, Neßelrath and Feld have proposed a semantic model to define the application logic of context-aware applications [29]. Their approach has focused on the annotation of dialogues, simulating human-computer interaction as human-human communication. It supports the specification of multimodal dialogue applications; systems that incorporate multiple input and output devices. Although these different examples could prove the advantages of using graphs to systematize the process and formalize the contents of UI design, they also cast light on the fact that different approaches can be followed in the process of operationalization.

In our study, semantic networks have been used to both analyze relations between different information elements and to specify design decisions. In contrast to only using UCD, or even to using UCD in combination with set- and graph theory, analysis of semantic networks helped to identify meaningful context conditions and aided explicit specification of context-dependent UI adaptation. This resulted in the design of three context-dependent UI adaptations. Analysis of complex semantic networks, however, can be a complicated tasks. Especially in the cases where the semantic network contains a large amount of information elements and relations among them. In our work, we used Microsoft Visio 2010 to develop the graphs used to specify the UI. Although this tool helps to visualize graphs, it is not an efficient tool to analyze more complex semantic networks. In future work more advanced semantic network visualization tools can be considered to better support analysis of the semantic network. Examples of semantic network visualization tools are found at www.cytoscap.org, www.ontopia.net, and www.gephi.org.

4.7 Conclusion

The research presented in this chapter had dual objectives. On the one hand, it has developed a widely applicable theoretical framework of how to complement UCD with formal modeling as a method to develop UI concepts. It has shown that insights concerning the deficiencies of current systems and formal modeling methods used for IE can be a robust basis of formulating concepts of efficient UIs to enhance operators' SA. On the other hand, this chapter presented the implementation of the UI concepts in a traffic control simulator environment to serve as testable prototypes. This showed that it is feasible to implement the theoretical formal modeling frameworks in a practical UI designed through UCD. IE steps provided reasons to adapt the UI developed through UCD only. In the next chapter we will use the developed prototypes to validate the proposed IE approach by studying their usability and the effects of the UIs on operators' SA, task performance, and workload.

Evaluation of our approach has revealed that combined use of set theory, graph theory, and semantic networks helped to (i) support identification of overlapping information and relations between information elements, (ii) design information fusion and both static and context-dependent adaptable content interaction within and between UI windows, and (iii) make design decisions explicit by offering a structured approach for specifying design rules. Our case study has shown that the use of semantic networks enabled the development of context-dependent UI adaptation. To fully profit from the advantages of semantic networks, we propose to consider the use of a semantic network visualization tool.

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This chapter is based on:

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CHAPTER 5

Research Cycle 4

VALIDATING INFORMATION ENGINEERING AS A MEANS TO IMPROVE SITUATION AWARENESS SUPPORT

Chapter 4 presented information engineering (IE) as a means to improve systems' ability to support operators' situation awareness (SA). Application of set theory, graph theory and semantic networks was proposed, which resulted in the development of three UI concepts. These concepts were implemented as testable prototypes in a nautical operational network management (N-ONM) workplace simulator. This chapter focuses on the validation of IE as a means to improve supporting operators' SA by testing the usability and impact of the prototyped UIs. Both usability and impact were validated using data from simulator tests, in which twenty N-ONM operators executed tasks in three challenging traffic management scenario's. Firstly, the applied validation approach is described in section 5.1. Section 5.2 addresses the usability of the UI design concepts, for which we used semi-structured interviews with N-ONM operators after task execution. The impact of the UI prototypes on operators' SA, task performance, and workload is discussed in section 5.3. This validation step is based upon data logged during task execution, including data logged by the simulator system and data logged by the test leader and observant. In section 5.4 we discuss to what extent the proposed IE approach aided to address the deficiencies that were identified with the existing systems. In the conclusion in section 5.5 we discuss the results of the three validation steps to conclude whether the proposed IE approach aids designers in addressing the deficiencies identified with existing systems.

5.1 Objective and approach of validation

The goal of our validation study was to validate the proposed IE approach as a means to improve support of operators' SA. Application of the IE approach resulted in the development of three IE-based UI concepts. These UI concepts have been operationalized as testable prototypes in a N-ONM workplace simulator. In this chapter, we evaluate the application of the prototypes. Three aspects were considered in this validation study. Firstly, the usability of the UI prototypes was validated. Secondly, the impact of the prototypes on operators' SA, task performance, and workload was validated. As a third step, the results of the first two validation steps were used to evaluate whether the prototypes were successful in overcoming the identified deficiencies of support of operators' SA. We expect that application of the IE approach increases the usability of UIs and has a positive effect on operators' SA, task performance, and workload. We assume that increased use of IE methods decreased the amount of deficiencies of support systems. Our validation is based on the principle of reasoning with consequences, see Figure 5.1. The tested prototypes were derived from the theory based UI concepts. If the outcome of testing the prototypes is in line with our expectations, than we can assume that the underlying UI concepts and IE approach are valid as well.

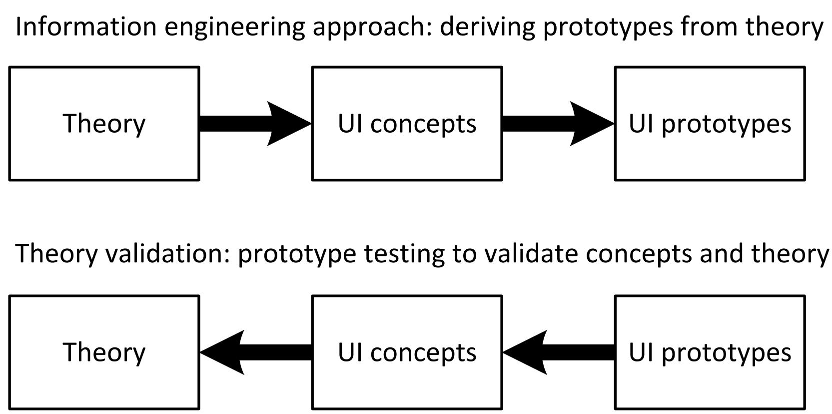

Figure 5.1 Validation approach: reasoning with consequences

5.2 Usability of the UI prototypes

The objective of the usability testing was to conduct an empirical validation of the performance of applying IE to design systems to support operators' SA. We expected that application of the proposed IE approach increases the usability of UIs. The three implemented prototypes differed in the extent to which the IE approach was applied. The development of the coherent UI prototype was solely based on the utilization of set theory to ensure coherency in content and visualization of information in the different UI windows. The integrated UI prototype was based on the utilization of set theory and graph theory to capture the syntactic relations between information elements used in the different UI windows. For designing the context-dependent adaptable UI, these methods were extended with application of semantic networks to capture semantic relations between information elements. If the context-dependent adaptable UI indeed outperformance the other UI prototypes and / or the coherent UI performs the least in terms of usability, than we can conclude that the IE approach and IE-bases UI concepts are valid means to improve system usability as well.

To validate the usability of the UI prototypes, we evaluated to what extent they supported N-ONM operators in executing N-ONM tasks. Besides, we evaluated the utility of the UI prototypes in terms of workload, speed of task execution, and the risk of making mistakes as experienced by the operators. Usability validation consisted of the following steps:

- To validate if the simulator environment is well equipped for usability testing.
- To validate if N-ONM operators are able to execute all identified N-ONM tasks when using the UI prototypes in the simulator environment.
- To conduct semi-structured interviews with operators who took part in the simulator testing to gain insight in their satisfaction in (i) how the UIs support N-ONM task performance, (ii) their experienced workload, (iii) speed of task execution, and (iv) risk of making mistakes when using the different UI prototypes.
- To conduct a semi-structured interview with operators who took part in the simulator testing to gain insight in their satisfaction in working with the different UI features that were implemented to realize the different types of UIs .

5.1.1 SAMPLING SUBJECTS FOR USABILITY TESTING

For the usability testing of the UI prototypes we involved N-ONM operators who in real-life work in the same area of control as the one which was operationalized in the simulator. The total population of N-ONM operators working in this area is approximately 60 persons. They were considered to be suitable to complete the testing. To form a sample of the population, 20 of them were randomly selected. They were freed from traffic management duties by the company and could thus participate in our experiments. The randomly selected operators were not obliged to participate in the tests. Operators were free to quit the experiment at any time. Operators were not obliged to give a reason when they decided to quit and it would not be reported to their manager.

The majority of the involved operators was highly experienced and had prior experience as steersman and/or skipper, as shown in Tables 5.1. According to the operators' team managers, this is consistent with the entire population of nautical traffic management operators working at the Dutch Ministry of Infrastructure and the Environment.

Table 5.1 Participants' experience

Years of experience in traffic management:				
Category:	0 – 3 years	3 – 6 years	6 – 9 years	> 9 years
Frequency:	1	1	3	13

Experience as steersman or skipper:		
Category:	No	Yes
Frequency:	2	16

5.1.2 DESCRIPTION OF THE USABILITY TESTING ENVIRONMENT

The developed UI prototypes have been operationalized on a N-ONM simulator, as shown in Figure 5.1 and Figure 5.2. A real life 24-hour log data file recorded on May 27, 2015 (a representative day in terms of availability of the waterways, and vessel types and quantity) was used in the simulator to simulate the behavior of vessels. This file contained the details of all vessels on the waterway, including voyage-, casco-, cargo-, and position information for each vessel. The behavior of locks was simulated based on log files form 2014, by considering the measured average vessel processing time per lock.

The N-ONM tasks, presented in Chapter 3, were used to develop three 10-minute tutorials and three one-hour traffic management scenarios. The one-hour scenarios incorporated all the identified N-ONM tasks, as shown in Table 5.2.

The scenarios were implemented in the workplace simulator. Communication with stakeholders, such as skippers, emergency services, and colleagues, was imitated by subject matter experts (SMEs) using scripts. The N-ONM operators

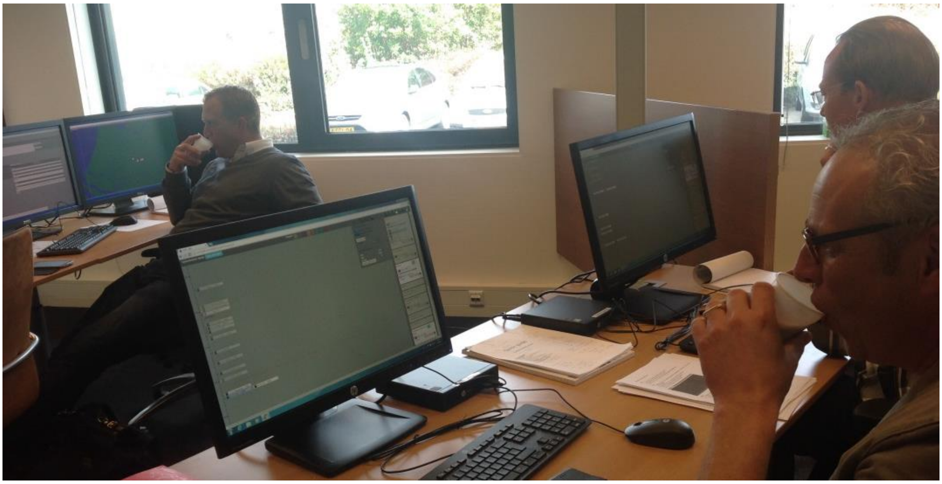

Figure 5.1 The simulator set-up with the N-ONM workplace (on the left) and the subject matter expert and observant desks (at the bottom and on the right)

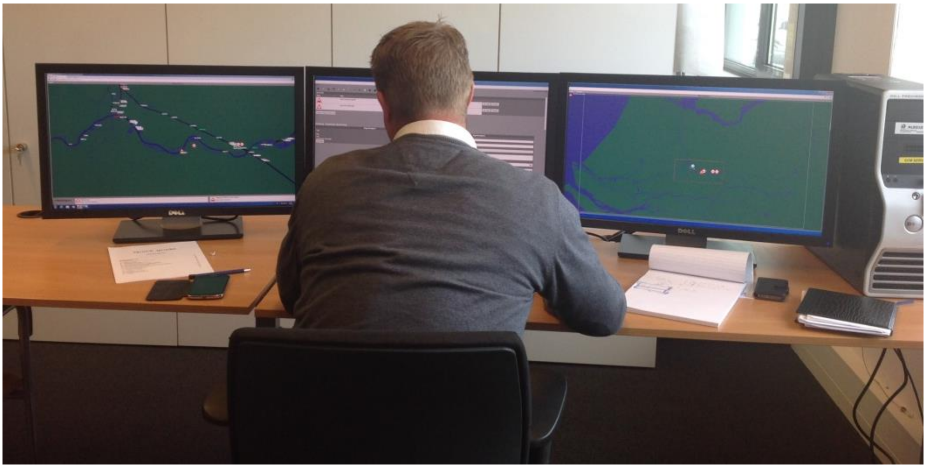

Figure 5.2 N-ONM workplace simulator, with integrated UI activated

could activate and terminate traffic measures on the simulator, which influenced the behavior of the simulated vessels and locks.

Table 5.2 Overview of N-ONM tasks

Tasks	Sub-tasks
Assess traffic conditions	Locate / identify shipping
	Follow shipping
	Observe network
	Register information
Inform stakeholders (skippers, emergency services, colleagues)	Provide traffic information
	Provide information in case of restrictions
Manage incidents	Take active actions for incident management
Plan traffic measure (planned restrictions)	Determine impact (planned restrictions)
Plan traffic measures (unplanned restrictions)	Determine impact (unplanned restrictions)
	Prepare traffic measures (unplanned restrictions)
Set / release traffic measure (planned and unplanned restrictions)	Take actions to remedy limitations and to effect traffic measures
	Set traffic measures
	Lift traffic measures
	Register information

5.1.3 VALIDATION OF THE USABILITY TESTING ENVIRONMENT

To validate if the simulator environment was well equipped for usability testing, we assessed the completeness and realism of the environment with 12 SMEs. This group of experts represented all identified stakeholders involved in the design, user testing, and maintenance of traffic management information systems, such as business analysts, nautical advisors, application managers, and system architects. The experts were asked to individually rate the completeness and realism of the user interfaces, using 7-point Likert scales. All SMEs evaluated the simulator with at least a 4 on both aspects. The variation in their answers is given in the box plots in Figure 5.3.

The ratings were discussed in a group discussion, where the experts unanimously agreed upon that the developed environment was elaborated enough to be used for testing the usability and impact of the UI prototypes. In relation to the completeness of the user interface, the SMEs mentioned that all information required for execution of the developed scenario's was available and therefore sufficient for meaningful testing. Due to the limited time available for evaluation of the UIs, they were unable to verify whether the UIs were sufficiently complete for all possible scenarios. This, however, was also not considered necessary for the planned experiments. The only concern related to the realism of the user interface was that the position of vessels on the waterways was not as realistic as in real traffic management systems. Although this would not hinder N-ONM task execution, they argued that this could negatively impact operators' user experience. They advised to inform operators prior to the experiments that this was a limitation of the simulator, and not a design decision to be implemented in practice. We followed their advice.

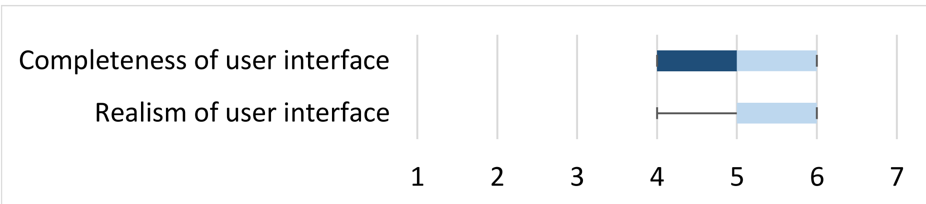

Figure 5.3 Box plot results of the evaluation by the involved experts. 1 = not complete / not realistic at all. 4 = sufficient for meaningful user testing. 7 = all desired information available / all conform reality.

5.1.4 USABILITY TESTING APPROACH

Scenario-based usability testing with semi-structured interviews was used to test the usability of the UIs. All operators followed the same procedure. First, the goal of the experiments was explained and all operators signed an informed consent form. After that, the three UI prototypes were presented and the operators completed three 10-minute tutorial scenarios, one for each UI concept. The concepts were referred to as MMI1 for the coherent UI, MMI2 for the integrated UI and MMI3 for the context-dependent adaptable UI. After ensuring their understanding of the three concepts, they executed each of the three one-hour scenarios. Counter balancing was used in combining the three different UI with the three different scenarios, and to change the order in which the different interfaces were used, see Table 5.3.

At the end of the day, the three UI prototypes were evaluated with the operators by conducting semi-structured interviews. The interviews followed the decomposition of system usability proposed by ISO 9241-11 Guidance on usability [1]. This norm proposes to decompose system usability in:

- Effectiveness: evaluation of the accuracy and completeness with which operator' goals can be achieved
- Efficiency: evaluation of the mental effort required to work with the system, speed of task performance, and whether the system is easy to learn
- Satisfaction of use: evaluation of operators' attitudes toward the used system

First, the interviewer asked operators about their overall impression:

1. How would you describe the user interface concepts? Were they overall realistic? Did they properly support the tasks at hand? Were they easy to learn?

The effectiveness of the UI prototypes was addressed as follows:

2. To what extent MMI 1 supported the N-ONM tasks? Could you execute all N-ONM tasks when using this MMI? If not, which tasks were not sufficiently supported?
3. To what extent MMI 2 supported the N-ONM tasks? Could you execute all N-ONM tasks when using this MMI? If not, which tasks were not sufficiently supported?

Table 5.3 Overview of the combinations of MMI and scenario used in a particular order in the various cases.

Case number	MMI order	Scenario order	Test 1	Test 2	Test 3
1, 7, 21	123	ABC	A1	B2	C3
2, 14, 22	213	ACB	A2	C1	B3
3, 9, 18, 27	132	BAC	B1	A3	C2
4, 10, 19	312	BCA	B3	C1	A2
5, 11, 24	231	CAB	C2	A3	B1
6, 15, 17, 26	321	CBA	C3	B2	A1

4. To what extent MMI 3 supported the N-ONM tasks? Could you execute all N-ONM tasks when using this MMI? If not, which tasks were not sufficiently supported?

The operators were provided with an overview of all N-ONM tasks to evaluate if all these tasks were supported by the different MMIs. This overview is the same as the one derived in Chapter 3 and given in Table 5.2.

The following question was used to interrogate about the operator's experiences with the efficiency of the different UI prototypes:

5. Which user interface do you consider to provide the best support in terms of workload, speed of task performance, and the risk of making mistakes?

Participants were allowed to answer with a specific MMI, with two MMI's preferred over one, or with 'no preference'. The responses of the operators to this question were subjective. We did not provide them with insights in their actual workload, speed of task performance, and made mistakes. Objective evaluation of the effect of the MMIs on workload and task performance was part of testing the effects of the MMI's, which is presented in Section 5.2.

The interviewer asked the following question to evaluate the user satisfaction:

6. Which user interface concept do you consider the best in supporting N-ONM tasks?

Participants were allowed to answer with a specific MMI, with two MMI's preferred over one, or with 'no preference'.

Finally, operators were asked to reflect on the features implemented in the UI prototypes to evaluate whether the UI prototypes were elaborated enough and to identify directions for further improvement. Participants were asked to specify how useful they considered the various features on a five-point Likert scale from '1 = very useless' to '5 = very useful'. They read the description of the feature, as given in chapter 4 but in Dutch, and the interviewer showed what was meant by the description by pointing this out in a screenshot of the interfaces. For each feature which was not considered useful, the interviewer asked whether the feature could be made more useful by redesigning it, or whether the feature was considered irrelevant for the N-ONM tasks.

5.1.5 RESULTS OF INTERROGATION ABOUT USABILITY

Overall impression

In their response to the open question 1, twelve out of twenty operators were positive about working with the three UI concepts, see Figure 5.4. Six operators considered the UIs sufficient for task performance but also indicated that there was room for improvement. Two operators were negative about the UIs in general. Their problem with the UIs was that the interfaces differed too much from their current systems, which made it difficult to get used to them. Both had more than 9 years of working experience. Positive comments about the UIs were that each of the three UI prototypes (i) were realistic (number of operators (n) = 7), (ii) provided sufficient support of N-ONM tasks (n = 9), and (iii) were easy to learn (n = 9).

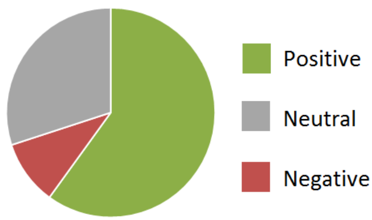

Figure 5.4 Pie chart of questions 1: operators' overall impression

Evaluation of the effectiveness of the UI concepts

To the question concerning the extent of support provided by the implemented coherent UI for the N-ONM tasks, operators replied that they found it difficult to assess traffic conditions (n = 7), especially to locate and identify shipping, and to register information (n = 4) by using this interface. Some of them argued that the Area of Control window in this prototype had little added value (n = 5). The coherent UI was considered rather limited and difficult to work with by some operators (n = 3), and finding the required information to assess traffic conditions and determine impact of (un)planned restrictions with this interface was experienced as time-consuming (n = 3).

To the question asking about to what extent the implemented integrated UI supported N-ONM tasks, operators replied that they could quickly enough find required information to access traffic conditions and determine impact of (un)planned restrictions (n = 8). Some of them replied that the interaction between windows worked well (n = 4). In contrast to the coherent UI it provided good support of registering information (n = 4) and supported operators in locating and identifying vessels (n = 4). One operator reported that he did not use the interaction between the vessel information overview window and the maps. Operators considered the integration of all geographic information in one big map as easy to work with (n = 7). The integration of different types of information in one map according to a number of them made it easier to observe the network and to provide traffic information (n = 4). One operator reported that the map could also contain too much information if all information layers were made visible. In our default settings, this was not the case. In contrast to MMI1, none of the operators responded that MMI2 did not provide sufficient support to execute N-ONM tasks.

To the question concerning to what extent the implemented context-dependent adaptable UI supported N-ONM tasks, operators replied that the context-dependent visualization of an extra Area of Focus window (Area of focus 2: displaying the location of events) was considered the most valuable feature of this concept (n = 5). The location of 'Area of Focus 2', on top of the default Area of Focus map, was evaluated less positive. For the location of the Area of Focus 2 in relation to the default Area of Focus map and Area of Control window, see Appendix VIII. One operator mentioned that the extra window covered relevant information relevant in the default Area of Focus window. Two operators preferred displaying this second Area of Focus window in the Area of Control window instead of on top of the other Area of Focus window. Two operators thought that this second window did not have an added value. The presented prognosis information was considered difficult to interpret (n = 4). Information about traffic density was not considered to be of use (n = 5). Instead, some operators preferred information about the duration of events (n = 2) or waiting times for locks (n = 3). Only one operator reported to have used the presented prognosis information and considered this valuable. In contrast to MMI1, none of the operators responded that MMI3 did not provide sufficient support to execute N-ONM tasks.

Evaluation of the efficiency of the UI concepts

Concerning the effects of the UIs on efficiency of task performance, ten out of twenty operators experienced a higher workload and lower speed of task performance with the coherent UI than with the other two UIs (Figure 5.5). The rest of the operators experienced no difference on these two aspects. Six operators reported a higher risk of making mistakes when working with the coherent UI instead of the other UIs. 13 operators did not perceive any difference in terms of the risk of making errors at using the different prototypes. Only one operator suggested that a coherent UI could result in fewer errors than the other two interfaces. He did not experience this during the tests, but reasoned that this could be the case because this interface requires the users to memorize more, and type in names and locations, instead of clicking on icons. Users could be unaware that they clicked on the wrong icon, he argued.

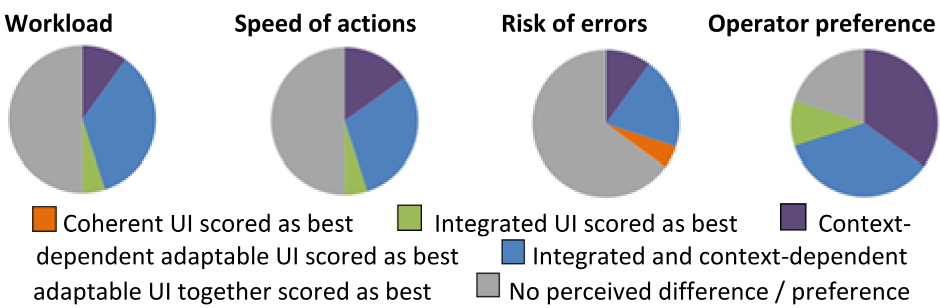

Figure 5.5 Pie charts evaluation of user interface concepts questions 5 and 6

Evaluation of operators' satisfaction

As shown in Figure 5.5, none of the operators replied that they preferred the coherent UI prototype when they were asked which UI provided the best support of N-ONM tasks. Two operators indicated that the tested prototype of the integrated UI provided the best support of N-ONM tasks. Seven operators regarded the integrated UI prototype and the context-dependent adaptable UI prototype as equally suitable. Seven operators replied that the context-dependent adaptable UI prototype provides the best support of N-ONM tasks. Four operators did not have a clear preference.

Evaluation of the implemented features

The results of the evaluation of the features used to implement the UI prototypes are given in Figure 5.6. This evaluation shows that all operators scored Feature 1, coherent UI design, with 3 or higher. All operators were neutral or positive about redesigning their current interface towards a coherent UI prototype. Feature 5, the possibility to filter the vessel overview window based on the estimated time of arrival of the vessels in a particular location, was evaluated as the least useful feature of the features 1 – 6 which together form the integrated UI prototype. Most operators scored the other features of the integrated UI prototype with a 3 or higher; they were considered useful by most of the operators. The Feature 7, context-dependent displaying a relevant location in a second area of focus window, was the only extra feature of the context-dependent adaptable UI prototype, which was considered useful by most of the operators. In addition, several suggestions were made about how to improve the usefulness of the other features of the context-dependent adaptable UI prototype. For Feature 8 (prognosis information) a total of eight suggestions for improvement were given, of which four were related to showing information about waiting times near locks. For Feature 9 (alternative routes), a total of 14 improvement suggestions were given, of which nine were related to differentiating routes per (types of) vessel(s). Analysis of the response to the open questions shows that, although the current implementation of the prognoses information and displaying of alternative routes was not considered very useful, approximately half of the operators considered these features valuable after improving their implementation.

Putting everything together we conclude that the three implemented UI prototypes were considered to be an improvement compared to currently applied user interfaces. Operators experienced several imperfections at testing the proposed coherent UI prototype. Seven out of twenty operators

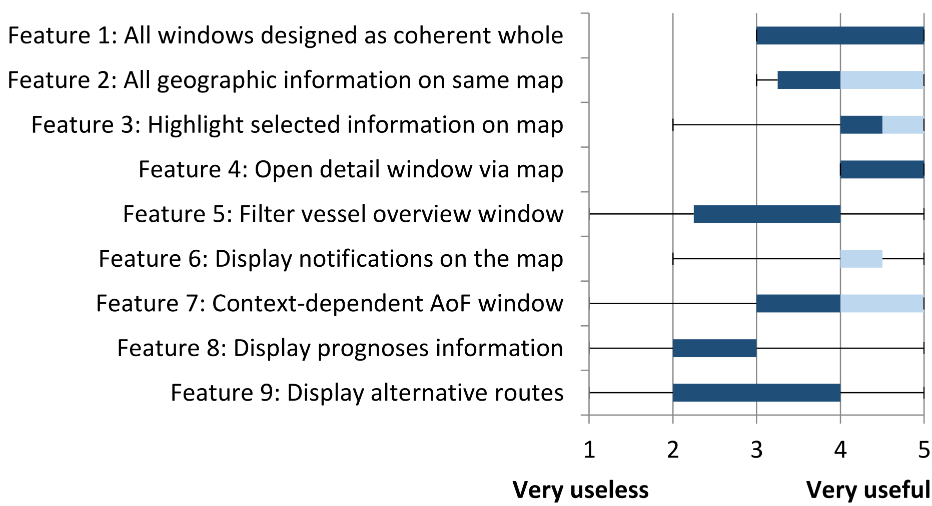

Figure 5.6 Box plot evaluation of the prototype features

experienced that this MMI did not sufficiently support N-ONM tasks. Limitations were found in support for accessing traffic conditions and for determining the impacts of (un)planned restrictions. According to all the operators, the other two MMI's did sufficiently support all N-ONM tasks. The difference between the integrated UI prototype and context-dependent adaptable UI prototype was found less significant, than it was expected. Nevertheless, the context-dependent adaptable user interface prototype was evaluated as most preferably by more operators than the integrated UI. At the same time it also showed more opportunity for improvement, than the two other implemented UI prototypes.

5.3 Effect of the UI concepts

The objective of validation of the effect of the implemented UI prototypes was to see if there was any significant difference between the effects of the UI prototypes. Three aspects were considered in evaluating the effect: (i) validation of the effect on operators' SA, (ii) validation of the effect on operators' task performance, and (iii) validation of the effect on operators' workload. The context-dependent adaptable UI prototype was expected to provide the best support of operators' SA, task performance, and workload, while the coherent UI was expected to provide the least support. If the measured effect of the UI prototypes is in line with these expectations, than we can assume that the IE approach and IE-based UI concepts indeed are valid means to improve support of operators' SA.

Two aspects were considered in evaluating the effect of the UI prototypes on operators' SA. Firstly, Situation Awareness Global Assessment Technique (SAGAT) developed by Endsley was used to measure which information was part of operators' SA knowledge [2]. Table 5.4 gives an overview of the queries used. Secondly, the identified differences were related to operators' required SA. SA knowledge which was not easy to access requires memory-based information processing and thus is part of operators' required SA. Information which is easy to access is no part of operators' required SA if display-based information processing is used.

Three aspects were considered in evaluating the effect of the UI prototypes on operators' task performance: (i) completeness of task performance was evaluated by counting the amount of required tasks that were executed, (ii) correctness of task performance was evaluated by scoring how well operators

Table 5.4 SAGAT queries for nautical operational traffic management (Original in Dutch)

1	Enter the location of all current events and provide a short description
2	Which of the following vessel types are the vessel type of vessels involved in an incident?
3	Which of the following names are the names of vessels involved in an incident?
4	Which of the following cargoes is the cargo of the vessels involved in an incident?
5	Which of the following names are of vessels with wounded persons on board?
6	Which of the following names are of vessels leaking fuel or cargo or that make water?
7	Which of the following locks are currently not, or only limited available
8	For which of the following locks do skippers over an hour need to take into account that there will be extra crowds and possible longer delays as a result of blockages or restrictions elsewhere on the waterway?
9	Which of the following service vessels is currently the closest to an incident?
10	How long will it take for the closest service vessel to be on site of the incident?
11	Which of the following vessels need to take into account that there are obstructions on their current route?
12	Which of the following restrictions apply to a motor cargo (length 85.00 m, width 9.60 m, height 7.90 m, depth 1.30 m) that is currently at lock Weurt, when she wants to arrive at the Port of Amsterdam as quickly as possible?
13	Which of the following routes is best advised to a motor tanker (no cones, length 109.00 m, width 11.40 m, height 6.00 m, depth 2.25 m) which plans to depart in one hour from the Port of Rotterdam towards Enschede?
14	Which of the following routes is best advised to a container vessel (length 135.00 m, width 17.40 m, height 10.30 m, depth 2.10 m) that plans to depart in one hour from the Port of Rotterdam towards Duisburg in Germany?

executed required tasks, and (iii) speed of task performance was evaluated by calculating how quickly operators executed required tasks.

Raw NASA Task Load Index (RTLX) was used to measure six aspects of subjective workload [3]. Since the involved operators were all native Dutch speakers, we translated the questions as given in Appendix IX. Firstly, the data was analyzed to identify if there was any significant difference between the effects of the UI concepts on workload. Secondly, we evaluated if the measured workload scores were high or low in comparison to studies of similar tasks. Because no RTLX scores of other studies concerning nautical traffic management have been found, we compared our scores to the scores reported by Grier [4]. Her analysis of 1173 reported workload scores showed that 80% of the these were between 26.08 and 68.00. Of those task environments which were taken into consideration by Grier, process control is the most relevant one if we want to compare the outcome of our experiments with other workload scores. For 38 process control test cases, the reported percentile ranks were 25th: 31.91, median: 42.00, and 75th: 51.83 [4]. If the scores obtained in our experiments remain well below this reference range, then we can safely say that no high workload was observed in the test.

5.2.1 SAMPLING SUBJECTS FOR TESTING THE EFFECT

The sample population for our experiments consists of all N-ONM operators who in real life work in the same area of control as the one which was operationalized in the simulator. This is a small population which consists of approximately 60 operators. Previous research using SAGAT has shown that an adequate within-subject test design for measuring statistically significant differences in operators' SA requires between 30 and 60 samplings per SA query across subjects and trails with each design option [2]. The amount of samplings per SA query depends on two aspects: number of cases (operators involved) and number of samplings in each case. Since it was impossible to include the entire sample population in our experiments, we included two freeze probes in each scenario. To obtain 60 samplings per SA query thus required to involve 60 : 2 = 30 participants. The aim of our study therefore was to involve 30 operators. We indeed scheduled 30 experiments. Unexpected circumstances, however, resulted in last minute cancelation of 10 experiments. We therefore ended with 20 experiments = 20 * 2 = 40 samplings per SA query.

Since counter balancing was used in combining the three different UIs with the three different scenarios we, however, could not use all 20 cases in our data analysis. For comparing MMI1 with MMI2, we had 18 cases, is 18 * 2 = 36 samplings available, see Table 5.5. Data of case 6 was not available because of errors made by the test leader. Four SMEs were involved as test leader, responsible for imitating communication using scripts. One SME, however, had only limited training prior to the experiments and only participated once. Data of this experiment, case 3, were also excluded. The data of four participants only included test results for experiments with the coherent and integrated UI, because of bugs in the simulator system. For comparing MMI1, MMI2, and MMI3, we could use data of 12 cases, is 12 * 2 = 24 samplings per query available. Since our sample size (n = 12) is more than 5% of our total population (N = 60), we should apply a finite population correction. Consequently, our study might still be powerful enough to show significant differences when evaluating the differences between all three UI concepts [5].

5.2.2 SCENARIOS

The simulator environment, presented in section 5.1, was used to develop three realistic challenging traffic management scenarios for testing the effect of the UI prototypes. The scenarios were developed together with four SMEs. The SMEs aimed at providing highly similar scenarios in terms of structure, duration, traffic intensity, and level of difficulty. The content, however, differed (See Table 5.6). Each scenario included communication to handle the events, which were part of that scenario. Additionally, each scenario included

Table 5.5 Overview of cases. The 12 cases in '**bold blue**' were used for comparing all three UI concepts. The 18 cases in '**bold blue**' and 'regular black' were used for comparing MMI1 and MMI2. Cases in '*italic grey*' were not used for testing the effects of UIs.

Case number	MMI order	Scenario order	Test 1	Test 2	Test 3
1, **7**, **21**	123	ABC	A1	B2	C3
2, **14**, 22	213	ACB	A2	C1	B3
3, 9, **18**, **27**	132	BAC	B1	A3	C2
4, 10, **19**	312	BCA	B3	C1	A2
5, **11**, **24**	231	CAB	C2	A3	B1
6, 15, **17**, **26**	321	CBA	C3	B2	A1

questions from skippers who were not involved in those events. Communication was imitated by a SME using scripts. The simulator software informed the test leader when to start which communication script.

The simulator software logged all actions of the operators. Communication was logged by both the test leader and an observant. They could log foreseen

Table 5.6 Scenarios

Scenario A – Collision near Houten	**Time**
UI displays information about planned blockage of Lock Beatrix starting a 18:00 hours	16:00
Phone call about malfunction of Lock Bernardsluis	16:04
Freeze probe 1: SAGAT + RTLX	16:08
VHF communication about collision between Calidris and Fueltrans	16:11
Freeze probe 2: SAGAT + RTLX	16:21
Freeze probe 3: RTLX	depends
Scenario B – Fire near Culemborg	**Time**
UI displays information about planned blockage of Lock Hagestein starting a 17:00 hours	16:00
VHF communication about fire on board of Presco	16:04
Freeze probe 1: SAGAT + RTLX	16:16
Phone call about malfunction of Lock Prinses Irenesluis	16:21
Freeze probe 2: SAGAT +RTLX	16:34
Freeze probe 3: RTLX	depends
Scenario C – Vessel aground at Waal	**Time**
UI displays information about anchorage Ravenswaaij not available	07:00
VHF communication about Hercules VI run aground	07:05
Freeze probe 1: SAGAT + RTLX + Time jump communicated Time jump to 09:30	07:26
VHF communication about Hercules VI loose, release waterway	09:38
Freeze probe 2: SAGAT + RTLX	09:42
Freeze probe 3: RTLX	09:49

communication by clicking on items in a script. Unforeseen communication was logged as typed text. Examples of data logged by the system are given in Appendix X. The simulator software automatically started freeze probes to measure operators' SA and subjective workload.

5.2.3 EXPERIMENT PROCEDURE

Prior to the experiments, participants received a description of the research background, including an explanation on what tasks were included in the experiment. This information was repeated at the beginning of the experiments. Participants read and signed the informed consent form and filled in a survey about their work experience. After that, the three UIs were explained to the participants and they completed a 10-minute tutorial scenario for each UI. The UIs were referred to as MMI1 (coherent UI), MMI2 (integrated UI) and MMI3 (context-dependent adaptable UI). The participants then performed the N-ONM tasks in the three traffic management scenarios, in a counterbalanced manner. Each scenario took approximately one hour and was followed by a ten-minute break.

5.2.4 DATA ANALYSIS

Prior to the data analysis, a code book was developed to specify the relevant variables. The code book also specified where to find the data related to each variable in the raw data files and how to calculate the values of variables when this was required. The code book was used to transmit the raw data into an SPSS database for data analysis. This data transition was conducted by a colleague that was not aware of the research hypothesis to be evaluated to ensure that the research is independent of the researchers. The data transition was checked by the researcher who did the data analysis prior to the analysis. An example of the information in the code book is given in Appendix XI.

For data analysis, two aspects are relevant. First of all, we were interested in the question whether (and how big) there was an effect of the MMIs on operators' SA, task performance, and workload. To answer this question, the effect size was calculated. Data were analyzed by using a within-subject design. The data could not be considered normally distributed due to the relative small sample size. Two within-subject tests are commonly used for testing differences between conditions in human factors research if the assumption of normally distributed data is violated; Friedman's ANOVA is used for more than two categories and Wilcoxon Signed Ranks Test is used for two categories [6] [7]. Friedman's ANOVA only shows whether there is difference between the tested conditions, but does not shows where this difference occurs. For that purpose, a post hoc analysis is required. Wilcoxon Signed Ranks Test is commonly used as post hoc analysis for Friedman's ANOVA. Since our sample size ($n = 18$) is large relative to the population ($N = 60$), it is needed to apply a correction to the formulas used to compute standard error (SE). This correction is called the finite population correction (FPC), which is calculated by $FPC = \sqrt{(N-n)/(N-1)}$ [5]. The standard error must be corrected by multiplying it with FPC. To calculate the significant of the test statistic (T), Wilcoxon Signed Rank Test looks at the mean ($\overline{T}$) and standard error ($SE\overline{T}$) by the formula $Z = (T-\overline{T})/SE\overline{T}$ [7]. To apply FPC in case of Wilcoxon Signed Ranks Test therefore means that the test statistic Z needs to be divided by FPC. The formula used to calculate Friedman's ANOVA test statistic does not include standard error. Consequently, it is not possible to correct Friedman's test statistic with FPC. Therefore, we used Wilcoxon Signed Ranks Tests only in our analysis.

Pearson's correlation $r = Z/\sqrt{N}$ is commonly used as an effect size for Wilcoxon Signed Ranks Tests. Here Z = test statistics measured with Wilcoxon Signed Ranks Test and N = number of observation. Cohen gives the guidelines as given in Table 5.7 for evaluating effects sizes for Wilcoxon Signed Ranks Test [8] [9].

Table 5.7 Guidelines for interpreting effect size

Test type	Small effect	Medium effect	Large effect
Wilcoxon Signed Ranks Test	0.10	0.30	0.50

If an effect was found, then the second question was: how likely is it that there is a true effect in the entire population of N-ONM operators? Commonly, results are considered statistically significant if $p \leq 0.05$. In cases where an effect is found, but this effect cannot be considered significant, than we can't be sure at the 95% level that what we see is not due to a random fluctuation. It can be that there indeed is an effect, but than our sample was too small for statistically significant results.

5.2.5 THE IMPACT OF UI PROTOTYPES

Within-subject Wilcoxon Signed Rank Tests were conducted to evaluate if the UIs had a significant effect on operators' SA, task performance, and workload. The overview of calculated effect sizes and significance levels per variable are given in Appendix XII.

Level 1 SA knowledge

Data analysis shows that operators have a rather good Level 1 SA with all three MMI's, see Table 5.8. Required Level 1 SA depends on which MMI is used. Vessels' cargo information is rather difficult to access when working with MMI1 and easy to access when working with MMI2 and MMI3. With MMI1 this information consequently is part of operator's required SA, while with MMI2 and MMI3 operators can successfully use display-based information processing when dealing with vessels' cargo information. Indeed, Wilcoxon Signed Ranks Test shows that operators are significantly more likely to have vessels' cargo information as part of SA knowledge when working with MMI1 than when working with MMI3 (effect size = 0.52 and p = 0.00). Also the names of vessels involved in an incident are more likely to be part of operators' SA knowledge when working with MMI3 (effect size = -0.42 and p = 0.02). The differences found between MMI1 and MMI2 were small and not considered significant.

Table 5.8 Descriptive Statistics of Level 1 SA scores, maximum score = 11

		Percentiles		
	N	25th	50th (Median)	75th
SA.Level1.MMI1	18	7.9	8.6	9.3
SA.Level1.MMI2	18	7.8	8.9	9.6
SA.Level3.MMI3	12	7.4	8.7	9.6

Level 2 SA knowledge

Data analysis shows that operators have a rather good Level 2 SA with all three MMI's, see Table 5.9. With MMI1 it is difficult to assess which vessels need to take into account obstructions on their route, since both the location of vessels and the location of incidents are not easy to access with MMI1. Both MMI 2 and MMI3 display the location of incidents in the maps, and allow to highlight vessels' locations on the map by clicking a vessels name in the information overview window. Whether operators have this information as part of their Level 2 SA knowledge is measured with SAGAT query 11 and 12. Indeed, with Wilcoxon Signed Ranks Test we found a large effect that is statistically significant for query 11 (effect size = -0.52 and p = 0.00). With MMI1 operators are significantly more likely to correctly answer query 11 during a SAGAT freeze than with MMI2. With MMI1 operators can successfully use memory-based information processing to execute tasks related to Level 2 SA. With MMI2 operators more likely use display-based information processing. A medium effect was found when comparing MMI1 with MMI3 on both query 11 (effect size = -0.31 and p = 0.06) and 12 (effect size = -0.33 and p = 0.05).

Table 5.9 Descriptive Statistics of Level 2 SA scores, maximum score = 11

		Percentiles		
	N	25th	50th (Median)	75th
SA.Level1.MMI1	18	8.9	9.5	10.0
SA.Level1.MMI2	18	8.0	9.0	9.6
SA.Level3.MMI3	12	7.6	9.0	9.4

Level 3 SA knowledge

Data analysis showed that operators scored relatively low on Level 3 SA with all MMI's, see Table 5.10. Operators have insufficient Level 3 SA to successfully use memory-based information processing to execute tasks related to Level 3 SA. With MMI1 operators are significantly more likely to correctly answer query 13 during a SAGAT freeze than with MMI3 (effect size = -0.38 and p = 0.03).

Table 5.10 Descriptive Statistics of Level 3 SA scores, maximum score = 11

		Percentiles		
	N	25th	50th (Median)	75th
SA.Level3.MMI1	18	5.7	7.5	8.0
SA.Level3.MMI2	18	5.3	8.0	8.8
SA.Level3.MMI3	12	5.6	7.4	7.9

Speed of gaining SA knowledge

Wilcoxon Signed Ranks Test showed an effect of the used UIs on the time it takes for the operator to gain SA knowledge. With MMI2 operators are significantly quicker (median is 43 seconds) in opening an incident in the area of focus window than when using MMI1 (effect size = -0.34 and p = 0.04). See Table 5.11. Feature 4, which was available in MMI2 and MMI3, allowed operators to quickly open the detail information window of a vessel by clicking the icon of this vessel on the map. It therefore was expected that operators were quicker in opening vessels' detail information windows in case of an incident when using MMI2 and MMI3. However, several operators mentioned during the evaluation that they forgot to use this feature, while they did consider it useful or very useful. They expected to commonly use this feature once they are used to it. A ten-minute tutorial might have been too little to change the way in which they search for detail information. Indeed, no significant effect on the time it takes to open the information detail window was found. With MMI3 operators, however, are more likely to open the vessel's detail overview window (effect size = -0.34 and p = 0.05) than with MMI1. The trend for MMI2 is similar, but not significant (effect size = -0.20 and p = 0.24). Putting everything into the basket of validation, we conclude that MMI2 and MMI3 provide better support to quickly gain SA in cases of an incident than MMI1.

Table 5.11 Descriptive statistics of speed of opening an incident in the area of focus window (in seconds)

		Percentiles		
	N	25th	50th (Median)	75th
Speed.AoF.correct.MMI1	18	33	138	475
Speed. AoF.correct.MMI2	18	28	57	209
Speed. AoF.correct.MMI3	12	28	100	226

Completeness of task performance

Wilcoxon Signed Rank Tests shows that operators are more likely to report incidents through VHF when using MMI2 than when using MMI1 (effect size = -0.37 and p = 0.03). The opposite trend is found for setting traffic measures. Operators seem more likely to set traffic measures when using MMI1 instead of MMI2 (effect size = -0.34 and p = 0.04). The same trend is found when comparing MMI1 with MMI3. Communication through VHF and setting traffic measures are different actions with the same goal: informing skippers about the obstruction. Operators were supposed to perform both actions. We therefore cannot conclude which MMI provides best support of the higher goal; informing skippers about the obstructions.

Correctness of task performance

The data analysis shows that with all UI prototypes most operators were able to correctly answer the skippers questions related to Level 1 SA and Level 2 SA, see Table 5.12. Apparently, all MMI's sufficiently supported answering these questions. Several operators, however, were not able to correctly answer the skippers' questions related to Level 3 SA. The analysis shows a medium and significant effect of the used UI on accuracy in answering questions related to Level 3 SA favor of MMI3 (effect size = -0.33, p = 0.05) compared to MMI1. No significant difference was found when comparing MMI1 with MMI2.

Operators significantly more often execute the necessary actions in the required order when using an integrated UI instead of a coherent UI (effect size = -0.32, p = 0.03). The same trend is found when comparing MMI1 with MMI3. No difference was found when comparing MMI2 with MMI3.

Table 5.12 Descriptive statistics of scores for answering skippers' questions, in which answer correct = 1 and answer wrong = 0.

		Percentiles		
	N	25th	50th (Median)	75th
Question.LevelSA1.MMI1	18	1,0000	1,0000	1,0000
Question.LevelSA1.MMI2	18	1,0000	1,0000	1,0000
Question.LevelSA1.MMI3	12	1,0000	1,0000	1,0000
Question.LevelSA2.MMI1	18	1,0000	1,0000	1,0000
Question.LevelSA2.MMI2	18	1,0000	1,0000	1,0000
Question.LevelSA2.MMI3	12	1,0000	1,0000	1,0000
Question.LevelSA3.MMI1	18	,0000	,5000	1,0000
Question.LevelSA3.MMI2	18	,2475	,8350	1,0000
Question.LevelSA3.MMI3	12	,3725	1,0000	1,0000

Speed of task performance

Wilcoxon Signed Rank Tests shows that operators are up to minutes (median = 136 seconds) quicker in speed of communication with priority stakeholders when using MMI2 instead of MMI1, see Table 5.13. We conclude that MMI2 was validated to increase speed of operators' communication with priority stakeholders when compared to MMI1 (effect size = -0.44 and p = 0.01). A small effect was found when comparing MMI1 with MMI3, but the data cannot confirm that this effect is not due to a random fluctuation (effect size = 0.19, p = 0.18). This result might be due to the small sample size (n = 12) in combination with an extreme outlier (Speed.Communication.MMI3 = 1528) in the data of an operator using MMI3.

Table 5.13 Descriptive statistics of speed of communication (in seconds) with priority stakeholders

		Percentiles		
	N	25th	50th (Median)	75th
Speed.Communication.MMI1	18	381	485	657
Speed.Communication.MMI2	18	307	331	459
Speed.Communication.MMI3	12	309	384	545

Workload

Based on the results of the Wilcoxon Signed Rank Test, we can conclude that the UI prototypes do not differ in their impact on operators' workload. Comparing the test results with the reference data reported by Grier [4], we can safely say that no high workload was observed in the tests, see Table 5.14.

Table 5.14 Average of RTLX scores and reference data of process control test cases taken from Grier [4]

	Percentiles		
Variable	25th	50th	75th
Reference data [4]	31.91	42.00	51.83
RTLX.Average.MMI1	12,54	24,50	38,42
RTLX.Average.MMI2	14,86	25,44	28,58
RTLX.Average.MMI3	15,96	24,36	28,71

5.4 Validation of the proposed information engineering approach with a view to the identified deficiencies

To validate IE as a means to improve support of operators' SA, we evaluated whether IE helped to address the identified deficiencies of current N-ONM support systems. Circumstances deficiencies that are inherent to N-ONM cannot be influences by system design. The deficiencies that (i) operators require a large amount of information, (ii) some information is only required sporadic, and (iii) some information is subject to change, are inherent to N-ONM and cannot be overcome by IE. Therefore, they are not taken into consideration in this validation. Although system design can influence working methods, we did not explicitly introduce uniform working methods in this research. The deficiency that operators do not follow a uniform working method therefore is not taken into account in this validation. In this section we discuss how IE aided to address the remaining deficiencies. Results from usability testing and testing the impact of the UIs are discussed to evaluate whether IE allowed to address these deficiencies.

Difficulty to access relevant information

All features implemented in the prototypes to represent the three IE-based UIs addressed this deficiency. Usability testing of the coherent UI showed that operators still considered it difficult to access information when working with this UI. None of the operators responded that the integrated UI and context-dependent adaptable UI provided insufficiently support of accessing information. Application of set theory in combination with graph theory to generate an integrated UI aided designers to design better support of accessing relevant information.

Current information presentation puts high demands on operators' ability to keep overview of a large area of control

Assessing information is the first step of gaining SA. Without assessing the required information, it is not possible to keep overview of the area of control. As discussed above, the coherent UI provided insufficient support of accessing information. Application of set theory to generate a coherent UI apparently was not sufficient to support operators in keeping overview of a large area of control. Application of set theory in combination with graph theory to generate an integrated UI aided designers to design better support of accessing information, and thus for keeping overview.

Evaluation of the effect of the UIs showed that there was not a significant difference between the integrated UI and context-dependent adaptable UI in supporting operators in keeping overview of the current situation in the area of control. A context-dependent adaptable UI, however, better supported the operators in projecting out the current situation. Combined use of set theory, graph theory, and semantic networks thus enabled designers to design more efficient information presentation to aid operators to gain insight in future activities of the elements in the environment and understanding of future environment dynamics.

Insufficient quality of information in systems

Our analysis of deficiencies of current support systems showed that there are multiple reasons for insufficient quality of information in systems, see Appendix IV. IE does not aid to overcome all causes of insufficient quality of information. The following of the identified causes of this deficiency, however, were addressed by applying IE methods: (i) contradictory information, (ii) redundant information, and (iii) information not logged. Application of set theory aided to identify that the same information is used in different UI windows. It provided support of preventing contradictory information by ensuring that information is updated in all UI windows if it is changed somewhere. Application of set theory and graph theory aided to reduce redundant pieces of information by designing an integrated UI. An integrated UI also provided better support of logging information. With an integrated UI, operators could click an element in their map to log information about this element. All known information about this element was automatically included in the log. Indeed, four operators reported that, in contrast to the coherent UI, an integrated UI sufficiently supported them in registering information.

System does not support efficient insertion of information

Logging is the main task for which N-ONM operators need to insert large amounts of information. In case of, for example, an incident, they need to log the location of the incident and the details about the vessels involved. With a coherent UI, all this information needs to be typed in. Application of graph theory allowed to map the relationships between information elements. Due to that, it was possible to design an integrated UI and context-dependent adaptable UI in which operators can insert all this information by a single mouse click per vessel. This made insert of information significantly quicker and removed the risk of typing errors.

Mental workload exceeds operator's mental capacity

Aspects mentioned by operators that contribute to a high mental workload for N-ONM tasks were (i) too many tasks during incidents, especially logging requires too much effort, (ii) during incidents many questions need to be answered to people who are unfamiliar with relevant details, and (iii) large amounts of phone calls cause distraction. Only the first aspect was addressed by applying IE methods. Set theory and graph theory were used to capture relations between information entities and to design interactions between UI windows. In the implemented prototypes, feature 4 allowed to open a log detail information window by right-clicking an object on the map. IE aided to automatically log all relevant information related to the clicked information entity. As such, the IE approach supported more efficient registration of information during incidents. No significant difference in mental workload, however, was found in testing the effects of the UI prototypes. The measured mental workload for all UIs was considered low. Aspect three, distraction by many phone calls, might be more sever in real life than during the scenarios in our test cases. The scenarios were designed to be challenging. All phone calls and VHF communication, however, were played by the same test leader. This lead to successive conversations. In real life, conversations could also take place at the same time. This may cause a higher mental workload in real life. Whether more efficient logging during incident does have a significant impact on operators' mental workload in such cases remains a question for further research.

N-ONM operators take wrong or no timely action

Aspects mentioned by operators that contribute to taking wrong or no timely actions were (i) time pressure, (ii) inexperience, and (iii) wrong order of executing necessary actions. Time pressure during task execution is inherent to N-ONM. IE cannot overcome that some operators are inexperienced. Only the third aspect can be influenced by system design. Application of set theory and graph theory aided designers in linking information elements to operators’ tasks. Insight in these relations aided the design of an integrated UI.

Evaluation of the effect of the UI prototypes on operators’ task performance showed that the UIs indeed influenced whether operators executed necessary tasks in the required order. Operators were more likely to execute tasks in the required order when using an integrated UI instead of a coherent UI. Evaluation of the effects of the UI prototypes showed that IE also aids to design better support of taking timely actions. An integrated UI and context-dependent adaptable UI provide better support to quickly gain SA in cases of an incident than a coherent UI. An integrated UI also had a positive effect on speed of communication with priority stakeholders.

ONM goals do not all receive the required amount of operator's attention

Application of set theory and graph theory aided to related information elements to N-ONM tasks. This revealed that the different maps which are available in existing N-ONM support systems are used for the same tasks. Feature 2 in the implemented prototypes integrated all information related to the same tasks in a single map. Feature 6 added extra information related to the same tasks to the map. By clustering information entities which are required for the same tasks, operators less easily overlook relevant information. This can aid operators in addressing all pertinent goals. Besides, the use of semantic networks aided to design a context-dependent adaptable UI which displays information that is related to currently active tasks. Evaluation of the completeness of task execution showed that the used UI indeed influences whether operators are likely to execute certain tasks. On the level of operators’ goals, however, no difference between the UI prototypes was found.

Operator receives no direct feedback on own actions

Semantic networks aided the design of a context-dependent adaptable UI which displayed information dependent on the situation. Part of the situation is whether operators activated traffic measures. When operators activated traffic measures that influenced the availability of the main traffic route, or measures that influenced prognosis information about traffic intensity at places in the network, then this information was automatically visualized. As such, the context-dependent adaptable UI provided feedback on the operator's actions. Evaluation of the effect of the UI prototypes showed that this UI provided better support of answering skippers questions related to future situations than the other UI prototypes. IE thus aided to address this deficiency, which had a positive effect on operators' task performance.

Some information is only available in operators' mind

Semantic networks aided to visualize prognosis information and information about available routes. With the coherent UI and integrated UI, this information was only available in operators' mind. Our results showed that visualization of this information aided operators to more accurately answer skippers' questions related to this information.

Time component of information not supported by system

As discussed above, semantic networks aided to design a UI that visualizes the time component of information. This had a positive effect on operators' task performance.

5.5 Conclusion

In this chapter we evaluated the coherent UI (MMI1), integrated UI (MMI2), and context-dependent adaptable UI (MMI3) prototype to validate if IE helped to improve systems' ability to support operators' SA. For MMI1, IE was only used to ensure coherency between the autonomic UI windows. For MMI2, IE furthermore was used to syntactically relate the different UI windows to create an integrated UI. For MMI3, IE was used to formally and uniformly represent both the semantic relations and the decisional constraints for context-dependent UI adaptations. Three aspects were taken into consideration in this validation: (i) whether application of the IE approach had a positive effect on the usability of the UI prototypes, (ii) whether application of the IE approach had a positive impact on operators' SA, task performance, and workload, and (iii) whether the IE approach aided to address the deficiencies that were identified with the existing systems. For all three aspects, the proposed IE approach is considered valid if MMI1 provided the least support and MMI3 provided the best support.

System usability was decomposed in effectiveness, efficiency, and user satisfaction. On all three aspects, MMI1 was evaluated as the MMI with the lowest usability, while MMI3 was evaluated best. Evaluation of the effectiveness of the UI prototypes showed that MMI1 did not sufficiently support all N-ONM tasks. The operators experienced limitations in support of accessing traffic conditions and in determining the impact of (un)planned restrictions. Both assessing traffic conditions and determining impact are examples of gaining SA. According to the operators, MMI2 and MMI3 did sufficiently support operators to execute all N-ONM tasks. Evaluation of the efficiency of the UI concepts showed that ten out of twenty operators considered MMI1 as less efficient than MMI2 and MMI3. None of the operators considered MMI1 the most efficient. Evaluation of user satisfaction showed that seven out of twenty operators preferred MMI3, seven operators preferred MMI2 or MMI3 and two operators preferred MMI2. None of the operators preferred MMI1.

Evaluation of the impact of the UI prototypes confirmed that MMI1 provided the least support of N-ONM tasks while MMI3 provided the best support. When using a coherent UI (MMI1), operators were slower in gaining SA knowledge, but likely to have more information as part of SA knowledge during freeze probes than when using an integrated UI (MMI2) or context-dependent adaptable UI (MMI3). More information as part of SA knowledge did not result in better task performance. The integrated UI (MMI2) was validated to effectively increase the speed of communication with priority stakeholders. Evaluation of the task performance of the operators revealed that operators significantly more often execute the necessary actions in the required order when using MMI2 or MMI3 instead of MMI1. MMI1 and MMI2 did not sufficiently support operators in answering the questions of skippers which required insight in future state of elements in the dynamic traffic management environment. MMI3 provided significantly better support of answering these questions. Usability testing showed that this effect potentially can be increased by further improving the implemented features. This research indicates that context-dependent adaptable UI features aiming to provide insight in available routes for specific vessels and prognosis information about waiting times near locks are most promising directions for future research. Reasoning with consequences, we concluded that IE indeed aids to enhance systems' ability to support operators' SA.

Application of the proposed IE approach aided to address ten of the identified deficiencies of current support of operators' SA. Our validation study showed that IE had a positive effect on eight of them. For two of the addressed deficiencies, we were not able to confirm that application of IE methods made a significant difference.

We can conclude that IE approach had a positive effect on (i) systems' usability, (ii) the impact of UIs on operators' SA and task performance, and (iii) was able to address deficiencies identified with existing systems. Overall we can conclude that the proposed IE approach is validated to aid designers in addressing deficiencies of systems' supporting SA.

5.6 References

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CHAPTER 6

OVERALL CONCLUSIONS, REFLECTIONS AND RECOMMENDATIONS

Nautical operational network management (N-ONM) is a new development in traffic management in the Netherlands. Consequently, no research has been done in how to support operators' situation awareness (SA) for N-ONM tasks. In this research we developed an analysis scheme that combines tested existing theories on SA to study required SA in cases when operators work with complex information systems. The analysis scheme points out which aspects need to be part of a holistic study of SA. Current existing methods to study operators' SA allow to study some, but not all aspects pointed out by the analysis scheme. To fill in the gap, we have developed a structured approach to combine the use of cognitive task analysis with observational research to identify deficiencies of current information systems. To overcome these deficiencies, we have developed design principles for three new user interface (UI) concepts. For this purpose we have complemented human factors research and user-centered design (UCD) with information engineering (IE) knowledge. We used the formalism of set theory, graph theory and semantic networks to model a coherent UI, integrated UI and context-dependent adaptable UI. To study the effects of these newly developed UI concepts, we have developed a N-ONM simulator. This simulator has been used to test the UI concepts with 20 operators. Analysis of the test results showed that IE aids to design better support of nautical traffic management operators' SA. A coherent UI was less effective in terms of speed of gaining SA and speed of task performance than an integrated UI and context-dependent adaptable UI. The context-dependent adaptable UI prototype provided better support of answering the skippers' questions that required level 3 SA from the operators, than the other two UI prototypes.

6.1 Overall scientific conclusions

There has been an increase in the amount and complexity of traffic on Dutch inland waterways. Traffic management is shifting from local traffic control to network traffic management. Due to these changes, operators in nautical traffic management centers experience difficulty to gain and maintain sufficient SA. Current user interfaces of traffic management information systems were developed for local traffic control. Optimizing these user interfaces to better support network traffic management is a possible solution to better support operators' situation awareness. The main question of this research project was:

> *How combined application of user-centered design and information engineering principles can enhance operators' situation awareness and support operators' task performance in nautical traffic management and similar contexts?*

In order to provide the answer to this main question, we answered the following key questions.

a. What defines required situation awareness in nautical operational network management context?

Existing theories on required SA defined it as the total set of information that operators ideally like to know to meet their goals. Existing methods to define required SA propose not to consider the influence of support systems on this total set of information. In cases of complex information systems, as is the case in N-ONM context, such a definition is not useful. Complex systems present large amounts of data and it is impossible for operators to have all relevant information as part of SA knowledge. SA support systems need not only to support operators in gaining SA, but also should reduce the amount of information which operators need to memorize. To support designing complex information systems supporting operators' SA, we presented the following distinction between information needs and required SA:

> ***Information needs*** *is all the information which is necessary to reach operator's goals successfully.*
>
> ***Required situation awareness*** *is the essential information about the dynamic environment, which operators need to have mentally available during task performance, where necessity and relevancy depend on information needs and the interaction between goals, tasks, individual factors and system factors.*

In line with this definition we have proposed an analysis scheme to support a systematic and structured study of required SA. The novelty of this scheme is that it (i) distinguishes information needs from required SA, (ii) concurrently considers factors influencing SA as factors influencing man-machine interactions that direct SA assessment, and (iii) points out that information processing strategies used for SA assessment will modify the required SA.

b. What are the deficiencies of current systems in supporting situation awareness of nautical operational network management operators?

Current methods to identify deficiencies of support of SA, e.g. the study of accident reports and the use of realistic simulated scenarios, were not applicable in N-ONM context. Application of the derived analysis scheme allowed to develop a novel structured approach for identifying deficiencies of current N-ONM SA support. This novel approach used syntactic-semantic processing of cognitive task analysis and observational research data to identify sources of SA errors. Application of this new approach revealed that operators: (i) experienced insufficient information quality (D.1.), (ii) had difficulty to access information (D.2.), (iii) were challenged by the need to maintain an overview of a large area of control due to the used information visualization techniques (D.3.), and (iv) did not execute all relevant actions (D.4.). These deficiencies were associated with human information processing, more specifically, with the support provided by visualization of large amounts of information.

At designing visualization of large amounts of information, we found that IE aids to handle complex information sets. We have proposed to address the deficiencies of SA support from an IE point of view. In doing so, we observed that the identified deficiencies were related to inefficient information handling. We observed that (i) simultaneous use of different UIs may lead to conflicting, confusing and unclear information, (ii) systems may display disjoint, fragmented, and redundant information entities, and that the interrelationships of information entities were not visualized, and (iii) operators' required SA is context-dependent, while UIs present information independent of the context.

c. ***Does combining user-centered design with an information engineering approach aid in the analysis and design of user interface concepts that overcome identified deficiencies?***

This thesis presented a widely applicable theoretical framework of how to combine UCD with IE in designing complex information systems to support SA. UCD proved to be useful in identifying operators' information needs and in designing the look and feel of UI design. Combined use of UCD and IE was shown to be necessary in specifying how the systems handles large amount of information to support human information processing. IE proved to be a robust basis of formulating concepts of efficient UIs to enhance operators' SA. Application of set theory, common graph theory and semantic networks resulted in the development of three UI concepts to overcome the identified deficiencies.

Application of operations of set theory has been proposed to facilitate the design of a coherent UI; a logical, consistent, orderly, and harmonious interface where multiple associated interfaces together form a coherent whole. Using formal modeling based on set theory proved to allow designers to make design decisions explicit and to specify relationships among information entities required for design decisions.

Combined use of set theory and common graph theory has been recommended in designing an integrated UI; an interface in which interrelated UI contents are structurally integrated and where content interactions of multiple user interface windows support operators' task performance. The formalism of set theory and common graph theory has proved to aid the specification of logical and semantic interrelationships of information entities and the functional interactions between information windows.

Semantic networks have been shown to support to design and specify a context-dependent adaptable UI: an interface which captures context information, assesses the implications of context, and accordingly adapts the interface contents and compositions to best support operators' task performance in the given context. We proposed to use semantic networks to (i) map descriptive information entities which describe the total of semantic relationships between information entities that play a role in a particular situation, and to (ii) define prescriptive information elements which define the conditions relevant for context-dependent decision making.

d. Does operationalization of the developed user interface concepts of complex information systems result in a functional design?

The theoretical UCD and IE based UI concepts were implemented as testable prototypes in a N-ONM workplace simulator to test their feasibility and applicability. Evaluation of the operationalization of the developed UI concepts has shown that application of set theory, graph theory and semantic networks helped to (i) identify overlapping information, (ii) specify relations between information elements, (iii) design meaningful information fusion, (iv) design both static and context-dependent interaction within and between UI windows, and (v) specify design rules. More specifically, application of set theory has been shown to support designers in preventing presentation of (i) conflicting information in different UI windows, and (ii) confusing information due to different ways of representing similar or the same data. Application of graph theory helped to identify relations among information elements, which supported efficient integration of information and to reduce displaying disjoint information element. Graph theory has also been show to support designers in identification of meaningful interactions between different UI windows. Semantic networks proved to be useful in identifying meaningful context-dependent UI adaptations.

Evaluation of the resultant prototypes proved that it is feasible to implement the theoretical UI concepts in practice. N-ONM operators were able to use the implemented UI prototypes to execute N-ONM tasks. We conclude that the UI concepts are valid in practice and resulted in a functional design.

e. Does the proposed IE approach aid to enhance systems ability to support operators' situation awareness, task performance, and workload?

In order to evaluate the validity of the proposed IE approach, we investigated (i) the usability of the implemented UI prototypes, (ii) the impact of the UI prototypes on operators' SA, task performance, and workload, and (iii) the extent to which the approach aided to address the identified deficiencies of existing N-ONM support systems. Evaluation of usability showed that the IE approach had a positive effect on the effectiveness, efficiency, and user satisfaction. Evaluation of the impact showed that the IE approach aided to enhance systems ability to support operators' SA and task performance. A positive impact of the IE approach on operators' workload could not be confirmed. Validation of the extent to which the approach aided to address the identified deficiencies showed that it aided to address ten of the identified deficiencies of existing support systems. Our case study showed that IE had a positive effect on eight of those deficiencies. For two of the addressed deficiencies we were not able to confirm that application of IE methods made a significant difference. Reasoning with consequences, we concluded that the propose IE approach is validated to enhance systems ability to support operators' SA and task performance.

6.2 Propositions

In line with the Delft University of Technology Doctoral Regulations, four propositions have been formulated which capture the main scientific contributions of this thesis. The propositions are as follows:

1. *A holistic understanding of the influences of man-machine interactions is needed at investigating situation awareness of operators working with complex information systems.*

Understanding criteria for proper SA requires viable insight in the interaction between the operator and their task environment. When operators work with complex information systems, then the interaction with the task environment takes place through these systems. The man-machine interactions direct operators’ SA assessment, which influences both operators’ SA knowledge as operators’ required SA. The man-machine interactions themselves are influenced by operators’ goals and task, by individual factors, and by system factors. All these aspects need to be taken into consideration when investigating situation awareness of operators working with complex information systems.

2. *An analysis scheme that distinguishes information needs from the required situation awareness increases the efficiency of exploring deficiencies of supporting situation awareness by complex nautical traffic management systems.*

Only if required SA to achieve operators’ goals is properly specified, examination of higher or lower degrees of SA knowledge or loss of SA is meaningful. In cases of complex information systems, it is impossible for operators to have all relevant information as part of SA knowledge. Studying SA in cases of large amounts of information requires to understand (i) how factors influencing SA influence man-machine interactions, (ii) that man-machine interactions direct SA assessment, and (iii) that strategies used for SA assessment modify required SA. If display-based information processing is used, then information which is part of information needs does not need to be part of required SA.

3. *The information engineering approach proposed for designing coherent, integrated, and context-dependent adaptable user interfaces not only aids designers in designing information visualization, but also systematizes the development process of interface contents.*

Combined use of UCD and IE methods allowed to design coherent, integrated, and context-dependent adaptable user interfaces for N-ONM. IE principles allowed to (i) map pieces of information to parts of the system, (ii) to reduce the disorganized, fragmented and redundant pieces of information, and (iii) to define the conditions relevant for context-dependent decision making. IE aided designers in their analyses of which information to present where and when. Besides, IE allowed to specify design decisions, such as rules for consistency, which helped to systematize the development process of interface contents.

4. *The specification of syntactic and semantic relations between information entities enhances the ability of nautical traffic management systems to support situation awareness and task performance of operators.*

In this thesis we showed that steps to specify syntactic relations between information elements had a positive effect on operator's speed of communication with high-priority stakeholders, and on the speed of gaining SA. IE steps to specify semantic relations between information elements had a positive effect on speed of gaining SA and on accuracy of task performance of tasks that require Level 3 SA.

6.3 Recommendations for Rijkswaterstaat

Rijkswaterstaat aims to improve and unify traffic management working methods and wishes to redesign the man-machine interactions in order to optimize operators' SA, workload and task performance. From scientific point of view we showed that a context-dependent adaptable UI provides better support of operators' SA and task performance than a coherent UI or integrated UI. From practical point of view, RIjkswaterstaat needs to carefully weigh the advantages of this UI with the downside that a context-dependent adaptable UI is more complex, and therefore more expensive, to design and maintain. Instead of evaluating which UI provides best support for operators' SA and task performance, RIjkswaterstaat needs to evaluate which UI concept provides sufficient support.

When using the coherent UI prototype, operators had difficulties with accessing traffic conditions and determining the impact of restrictions. These tasks are vital to proper N-ONM task performance. Additionally, our results showed that operators were minutes slower in communication with priority stakeholders and in speed of gaining SA when working with a coherent UI instead of an integrated UI or context-dependent adaptable UI. Besides, operators were less likely to execute actions in the required order when working with a coherent UI. We conclude that a coherent UI does not provide sufficient support of N-ONM tasks.

In comparing the impact of an integrated UI and context-dependent adaptable UI, the results showed a significant difference in support of answering skippers questions. The implemented context-dependent adaptable UI features supported operators in providing accurate information related to future availability of alternative routes and restrictions on the waterway. In the prototype, the implemented features had limited functionality. When developing context-dependent adaptable UI features to support answering skippers questions, designers should focus on features that aid to assess available alternative routes for specific vessels and to estimate traveling times for each alternative route. Besides system design, Rijkswaterstaat can aim to improve operators' ability to correctly answer skippers questions by training N-ONM operators. Thorough knowledge on characteristics, limitations, and common traveling times of all alternative routes helps operators to gain sufficient level 3 SA, which reduces the need for advanced support systems.

Overall we conclude that a meaningful first step in improving support of N-ONM is the implementation of an integrated UI. A coherent UI is considered insufficient to provide proper N-ONM support. The features developed to generate an integrated UI presented in this thesis were validated positively and most are sufficiently elaborated to be implemented. Only the feature to filter the vessel overview window should be further elaborated before actual implementation. In parallel, we advise to train N-ONM operators in gaining and maintaining required level 3 SA. After implementation of an integrated UI and additional training, it is advised to evaluate if more advances support systems are required to support operators in correctly answering skippers questions related to level 3 SA.

6.4 Recommendations for future research

This research work focused on how IE aids to design better support of N-ONM operators' SA. The research, however, was based on theories developed in a wide range of other contexts. SA theories are mostly developed in the fields of aviation, air traffic control, and process control. Other human factors theories, such as theories on operators' performance and workload, are developed in a wide range of work domains. The applied IE methodologies were also not taken from the traffic management domain. Since all steps in the process of designing these UIs were kept application domain independent, these results most likely are relevant for all contexts were visualization of large amounts of information to support operators' SA assessment is required. A potential next step in the research of IE as a means to better support operators' SA therefore is to apply the knowledge generated in this thesis in other command and control domains, such as in the field of process control, air traffic control, and aviation. Potentially, the knowledge generated in this research work is relevant for all cyber physical systems which have human in the loop.

SUMMARY

INFORMATION ENGINEERING FOR SUPPORTING SITUATION AWARENESS OF NAUTICAL TRAFFIC MANAGEMENT OPERATORS

Background of this research

Nautical operational network management (N-ONM) is a new form of corridor traffic management on Dutch inland waterways. N-ONM operators use a wide range of information systems to remotely manage a traffic corridor, such as the main route and alternative routes between Port of Rotterdam and Germany. N-ONM operators require an accurate and complete mental picture of the situation at the corridor. Such a mental picture of a dynamic environment is called situation awareness (SA). N-ONM operators experience difficulties at gaining and maintaining proper SA when using traditional nautical traffic management information systems. This research project aimed to improve systems' ability to support N-ONM operators' SA. A holistic understanding of SA knowledge and the effect of man-machine interactions on SA assessment is required when aiming to understand how to better support operators' SA.

The main challenge of N-ONM operators in SA assessment is to locate and process large amounts of information about the dynamic environment. Consequently, the main challenge of system designers is to design effective

information visualization to support users in perceptual and cognitive processes to interpret and understand the presented information. Designing for SA is commonly addressed by applying user-centered design (UCD) methods. UCD offers methods for acquiring user input in iterative design cycles. It, however, does not provide methods that aid designers in handling large amounts of information. Information Engineering (IE) on the other hand does offer methods for information handling in complex information systems, but limited attention has been paid to how IE supports designing for SA. This thesis aimed to investigate combined use of UCD and IE as a means to improve systems' ability to support operators' SA.

Research problem and questions

There is no clear standpoint in the current literature concerning how IE contributes to enhance systems' ability to support SA. Our overall research hypothesis was that combining UCD with an IE approach will aid designers in designing better SA support. The aim of this thesis was to investigate how an IE approach aids designers in the analysis and design of human-system interactions to support SA. The practical case of N-ONM operators experiencing difficulties to gain and maintain required SA was used to aggregate new knowledge and to validated developed methods and the effects of proposed design principles. We formulated the following main research question:

Q.0. *How combined application of user-centered design and information engineering principles can enhance operators' situation awareness and support operators' task performance in nautical traffic management and similar contexts?*

In order to provide an answer to our main research question, we decomposed it into the following working research questions:

Q.1. What defines required situation awareness in nautical operational network management context?

Q.2. What are the deficiencies of current systems in supporting situation awareness of nautical operational network management operators?

Q.3. Does combining user-centered design with an information engineering approach aid the analysis and design of user interface concepts that overcome identified deficiencies?

Q.4. Does the operationalization of the developed user interface concepts for complex information systems result in a functional design?

Q.5. Does the proposed IE approach aid to enhance systems ability to support operators’ situation awareness, task performance, and workload?

Q.5. Does the proposed IE approach aid to enhance systems ability to support operators’ situation awareness, task performance, and workload?

Research methods

A literature review was conducted to explore the knowledge domains that are relevant to define required SA in complex information systems context. From this literature study, an analysis scheme to study required SA in a holistic matter was derived. This analysis scheme was complemented with a method to process cognitive task analysis and observational research data to identify deficiencies of systems in supporting SA. The resultant approach was applied to N-ONM to identify deficiencies of supporting N-ONM SA. The logical properness and practical appropriateness of the analysis scheme were validated by evaluation of the practical case study.

Design steps were used to generate knowledge about potential user interface (UI) concepts to overcome the identified deficiencies. UCD was applied to design the look and feel of a UI that will support operators’ SA. IE methods were used to develop a structured approach for handling large amounts of information in designing UI concepts. IE was used both in analyzing relationships between information elements and in specifying UI design. Application of different IE methods resulted in the development of three UI concepts. We applied the generated UI concepts as testable prototypes in a N-ONM workplace simulator to validate that operationalization of the concepts results in a functional design.

Usability and impact of the implemented prototypes were validated in order to evaluate if the proposed IE approach helped to improve systems' ability to support operators' SA. Usability testing consisted of simulator tests with semi-structured interviews with N-ONM operators after task execution. Impact testing was based upon within-subject tests for measuring statistically significant differences in operators' SA, task performance, and workload. Input for impact testing was data logged during task execution. This included data logged by the simulator system, such as all operators' actions in using the system, and data logged by a test leader and observant, such as the content of communication. Results from usability and impact testing were used to validate whether the IE approach aided to overcome the deficiencies of the existing systems. Reasoning with consequences was applied to validate IE as a means to improve SA support. If prototype testing revealed that IE aided to improve SA support, then it is assumed that the underlying concepts and IE approach are valid as well.

Results

An analysis scheme to holistically study required situation awareness

Our literature review showed that studying SA in case of complex information systems requires to distinguish required SA knowledge from other relevant information. Existing theories, however, do not articulate this distinction. We therefore proposed the following definitions:

> ***Information needs*** *is all the information which is necessary to reach operator's goals successfully.*
>
> ***Required situation awareness*** *is the essential information about the dynamic environment, which operators need to have mentally available during task performance, where necessity and relevancy depend on information needs and the interaction between goals, tasks, individual factors and system factors.*

In line with these definitions, we developed an analysis scheme to support a holistic study of SA. This analysis scheme is derived from existing theories by critical synthesis, see Figure 1.

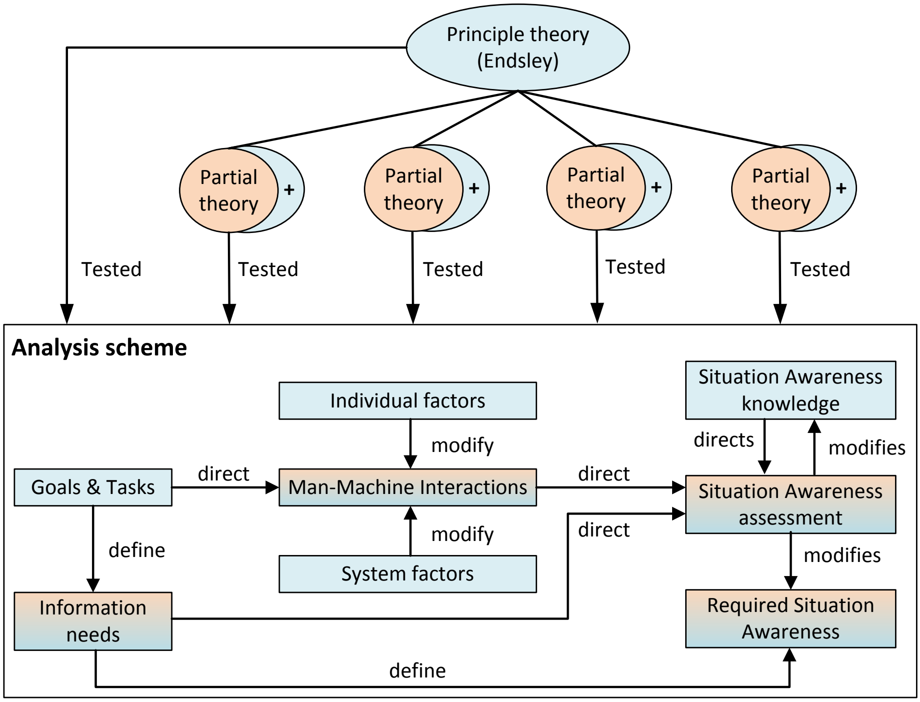


Figure 1 The process of combining tested existing theories in an analysis scheme to study required situation awareness in a holistic matter

An information elicitation approach to identify deficiencies

Common methods to identify deficiencies of supporting operators' SA are (i) analysis of accident reports, (ii) assessing operators' SA in simulated scenarios, and (iii) observational research. Accident reports and simulated scenarios are not always available, as was the case for N-ONM. Several researchers indicate that observational research is not sufficient to accurately rate SA. In this research, we used the derived analysis scheme to develop an alternative approach to identifying deficiencies. Cognitive task analysis and observational research were used to study all aspects of the analysis scheme. Our information elicitation approach used syntactic-semantic processing of the resultant data to identify deficiencies of supporting SA. Application of the proposed approach aided to identify deficiencies of current N-ONM practice. In total we identified 30 deficiencies, of which 23 were related to how the system interfaces support human information processing.

These deficiencies were clustered into four main groups:

D.1. Operators experience insufficient quality of information
D.2. Operators have difficulty to access information
D.3. The used information visualization techniques put a high demand on operators' ability to maintain an overview of a large area of control
D.4. Operators do not execute all relevant actions

Defining user interface concepts to overcome the four groups of identified deficiencies

UCD proved to be useful to identify which information operators need to reach their goals and to design the UIs' look and feel. It, however, did not sufficiently support designing information visualization of large amounts of information to support human information processing. In order to address the deficiencies related to support for human information processing, we addressed them from an IE point of view. This aided the development of three UI concepts:

- *A **coherent user interface** is a logical, consistent, orderly and harmonious interface. If there are multiple associated interfaces, then they together form a coherent whole.*
- *An **integrated user interface** uses information fusion and capitalizes on content interactions of multiple user interface windows. Interrelated user interface contents are integrated to support specific tasks assigned to the operators' role.*
- *A **context-dependent adaptable user interface** captures context information, assesses the implications of context, and accordingly adapts the interface content and composition to best support the pertinent tasks in the given context.*

The principles of set theory were used define the coherent UI. It allowed to map pieces of information to parts of the system, see Figure 2. In designing the integrated UI, we aimed to reduce the disorganized, fragmented and redundant pieces of information. For this purpose, we applied principles of set theory and common graph theory to specify the logical relations of information entities and the functional interaction between information windows. An example of a graph that was used in designing an integrated UI is given in Figures 3. Designing a context-dependent adaptable UI requires to describe the total of semantic relations between information entities to define the conditions relevant for context-dependent decision making. We used semantic networks to represent both the semantic relations and the decisional constraints, see Figure 4.

We implemented the developed concepts in a N-ONM workplace simulator to evaluate the usefulness of the concepts in practice. Firstly, we applied UCD to identify which information the N-ONM operators need to reach their goals and to design the look and feel of the UI concepts. After that, we applied the three IE-based UI concepts to the UCD-based UI design. Finally, we have developed a N-ONM workplace simulator in which we implemented a prototype of the developed concepts to demonstrate their feasibility and applicability (Figure 5).

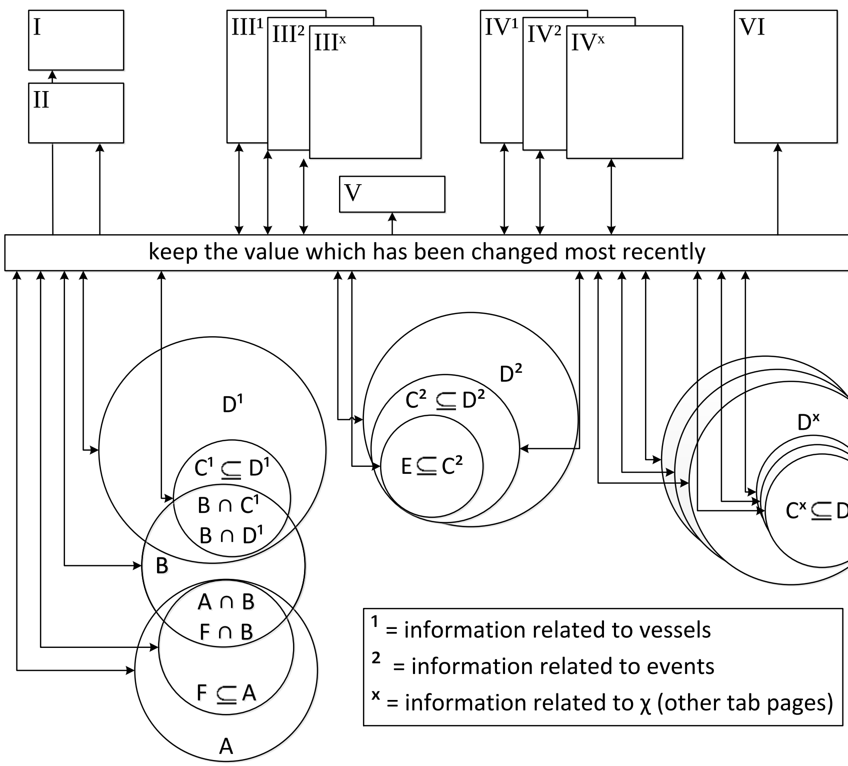


Figure 2 Coherent user interface specification based on set theory (the circles represent the information sets, rectangles the UI windows)

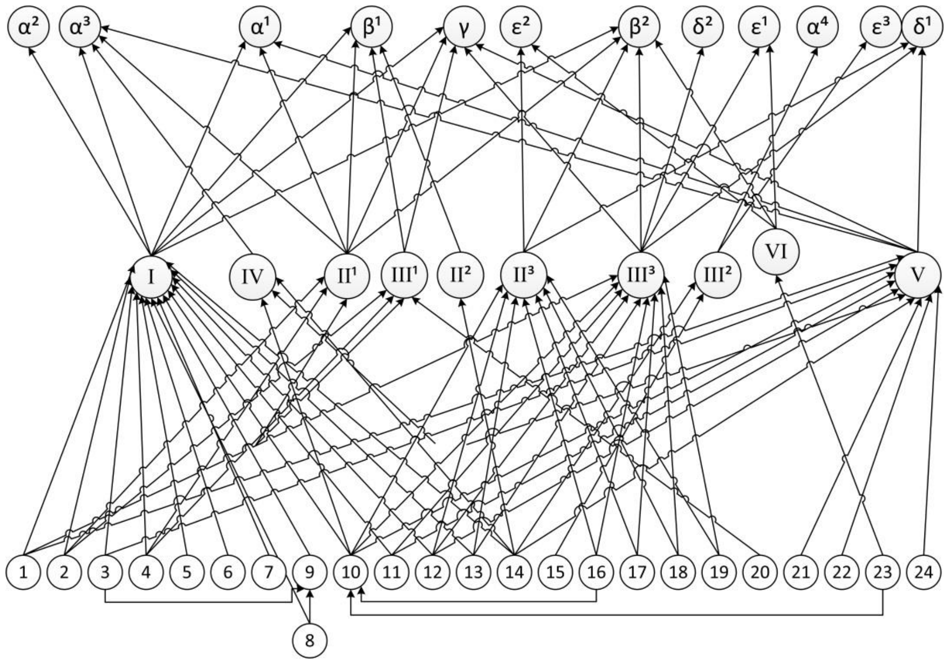


Figure 3 Content integration graph (CIG) of the developed integrated user interface for N-ONM tasks

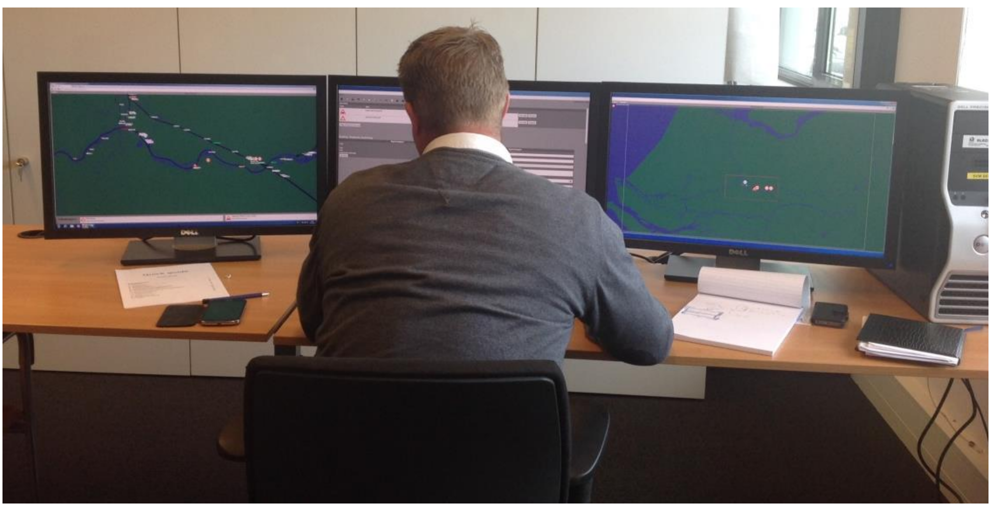


Figure 5 N-ONM workplace simulator, with integrated UI activated

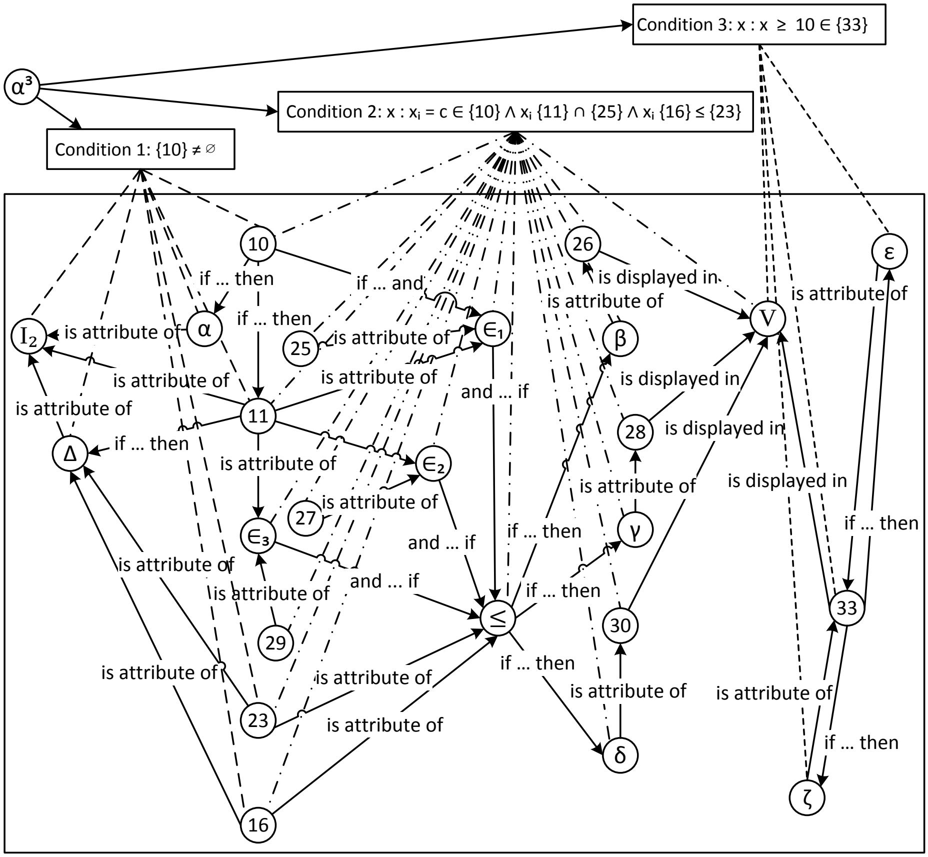


Figure 4 Context-dependency graph (CDG) of a context-dependent adaptable user interface for N-ONM tasks

Validating information engineering as a means to improve situation awareness support

Usability testing showed that the proposed IE approach had a positive effect on the effectiveness, efficiency and user satisfaction. The coherent UI provided insufficient support of assessing traffic conditions and determining impact of restrictions. The integrated UI provided better support than the coherent UI. The context-dependent adaptable UI was evaluated as the interface which provided the best support of N-ONM.

Evaluation of the impact of the UI prototypes on operators' SA, task performance, and workload confirmed the results of usability testing. When using a coherent UI, operators were (i) slower in gaining SA, (ii) slower in communication with priority stakeholders, and (iii) less likely to execute necessary actions in the required order compared to using an integrated UI or context-dependent adaptable UI. A context-dependent adaptable UI provided the best support of answering questions of skippers related to future states of the traffic management environment.

Application of the proposed IE approach aided to address ten of the 23 deficiencies related to support of human-information processing. Evaluation of the usability and impact showed that IE had a positive effect on eight of them. Reasoning with consequences, we concluded that the proposed IE approach is validated to aid designers in addressing deficiencies of systems' supporting SA.

Conclusions

To conclude the research work and results, we were able to derive the following propositions:

1. A holistic understanding of the influences of man-machine interactions is needed at investigating situation awareness of operators working with complex information systems.
2. An analysis scheme that distinguishes information needs from the required situation awareness increases the efficiency of exploring deficiencies of supporting situation awareness by complex nautical traffic management systems.
3. The information engineering approach proposed for designing coherent, integrated, and context-dependent adaptable user interfaces not only aids designers in designing information visualization, but also systematizes the development process of interface contents.
4. The specification of syntactic and semantic relations between information entities enhances the ability of nautical traffic management systems to support situation awareness and task performance of operators.

SAMENVATTING

INFORMATIE-ENGINEERING VOOR HET ONDERSTEUNEN VAN SITUATIEBEWUSTZIJN VAN NAUTISCHE VERKEERSMANAGEMENT OPERATORS

Achtergrond van dit onderzoek

Nautisch operationeel netwerkmanagement (N-ONM) is een nieuwe vorm van corridorverkeersmanagement op Nederlandse binnenwateren. N-ONM operators gebruiken een veelheid aan informatiesystemen om het verkeer op een corridor op afstand te regelen. Een voorbeeld van een corridor is de hoofdroute en alternatieve routes tussen de haven van Rotterdam en Duitsland. N-ONM operators moeten beschikken over een accuraat en compleet mentaal beeld van de situatie op de corridor. Zo'n mentaal beeld van een dynamische omgeving wordt situatiebewustzijn of situation awareness (SA) genoemd. N-ONM operators ervaren moeilijkheden bij het verkrijgen en onderhouden van een goede SA wanneer zij gebruik maken van traditionele nautische verkeersmanagementinformatiesystemen. Dit onderzoeksproject was gericht op verbetering van het vermogen van systemen om het SA van N-ONM operators te ondersteunen.

De belangrijkste uitdaging van N-ONM operators in het opdoen en onderhouden van SA is hun vermogen om grote hoeveelheden informatie over de dynamische omgeving te lokaliseren en verwerken. De belangrijkste uitdaging van systeemontwerpers is daarom het ontwerpen van een effectieve informatievisualisatie om gebruikers te ondersteunen in waarneming en in cognitieve processen voor het interpreteren en begrijpen van de gepresenteerde informatie. Een standaard ontwerpaanpak bij het ontwerpen van SA support is user-centered design (UCD). UCD biedt methodes voor het verwerven van input van de gebruikers in iteratieve ontwerpcycli. UCD biedt echter geen methodes die ontwerpers ondersteunen in het hanteren van grote hoeveelheden informatie. Informatie-engineering (IE) aan de andere kant biedt wel methodes voor het hanteren van grote hoeveelheden informatie in complexe informatiesystemen. Het wordt echter niet standaard ingezet voor het ontwerpen van systemen om het SA van operators te ondersteunen.

Onderzoeksprobleem en vragen

Er is geen duidelijk standpunt in de huidige literatuur over hoe IE bijdraagt aan het verbeteren van het vermogen van systemen om operators te ondersteunen in het opdoen en onderhouden van SA. Onze onderzoekshypothese is dat het combineren van UCD met een IE-benadering ontwerpers zal helpen in het ontwerpen van betere SA ondersteunende systemen. Het doel van dit proefschrift is om te onderzoeken hoe een IE aanpak ontwerpers helpt in de analyse en het ontwerp van mens-systeem interacties ten behoeve van het ontwerpen van SA support. De N-ONM casestudie waarbij operators moeilijkheden ervaren bij het opdoen en onderhouden van SA is gebruikt om nieuwe kennis op te doen en om de ontwikkelde methodes en de effecten van de voorgestelde ontwerpprincipes te valideren. We hebben de volgende onderzoeksvraag geformuleerd:

Q.0. *Hoe kan een gecombineerde toepassing van user-centered design en informatie-engineering het situatiebewustzijn en de taakuitvoering van operators werkzaam in nautisch verkeersmanagement en soortgelijke contexten verbeteren?*

Om een antwoord te geven op deze onderzoeksvraag hebben we de volgende subvragen gedefinieerd:

Q.1. Wat definieert het vereiste situatiebewustzijn in een nautisch operationeel netwerkmanagementcontext?

Q.2. Wat zijn de tekortkomingen van de huidige systemen in de ondersteuning van het situatiebewustzijn van nautische operationeel netwerkmedewerkers?

Q.3. Helpt het combineren van user-centered design en informatie-engineeringmethodes ontwerpers in de analyse en het ontwerp van gebruikersinterfaceconcepten voor het oplossen van geïdentificeerde tekortkomingen?

Q.4. Resulteert het in de praktijk toepassen van de ontwikkelde gebruikersinterfaceconcepten voor complexe informatiesystemen in een functioneel ontwerp?

Q.5. Helpt de voorgestelde informatie-engineeringaanpak bij het verbeteren van het vermogen van systemen om het situatiebewustzijn, de taakuitvoering en de werklast van operators te ondersteunen?

Onderzoeksmethodes

Een literatuurstudie werd uitgevoerd om de kennisdomeinen te verkennen die van belang zijn bij het definiëren van het vereiste SA binnen de context van complexe informatiesystemen. Uit deze literatuurstudie is een analyseschema afgeleid dat het vereiste SA holistisch benadert. Dit schema werd aangevuld met een methode voor het identificeren van tekortkomingen van systemen in het ondersteunen van SA. Deze methode maakt gebruik van cognitieve taakanalyse data en observationele onderzoeksgegevens. De methode is toegepast in de N-ONM praktijk om tekortkomingen van verkeersmanagementinformatiesystemen op het gebied van SA support te identificeren. De juistheid en praktische toepasbaarheid van het analyseschema zijn gevalideerd door evaluatie van deze praktische casestudie.

Voor het genereren van kennis over hoe de geïdentificeerde tekortkomingen van de systemen overkomen kunnen worden is gebruik gemaakt van *onderzoek-door-ontwerp*; het ontwerpproces voor het ontwikkelen van nieuwe gebruikersinterfaceconcepten leidt niet alleen tot nieuwe concepten, maar geeft ook inzicht in hoe beter te ontwerpen voor SA. UCD werd toegepast voor de vormgeving van een gebruikersinterface (UI) die operators ondersteunt op het gebied van SA. IE-methodes zijn toegepast om een gestructureerde aanpak te ontwikkelen voor het hanteren van grote hoeveelheden informatie bij het ontwerpen van UI-concepten. IE werd zowel bij het analyseren van de relaties tussen informatie-elementen als bij het specificeren van het ontwerp gebruikt. Toepassing van verschillende IE-methodes resulteerde in de ontwikkeling van drie UI-concepten. Deze UI-concepten hebben we geoperationaliseerd als testbare prototypes in een N-ONM werkpleksimulator voor het valideren dat toepassing van de concepten resulteerde in een functioneel ontwerp.

De bruikbaarheid en het effect van de geïmplementeerde prototypes zijn gevalideerd om te beoordelen of de voorgestelde IE-aanpak bijdraagt aan het vermogen van systemen om SA te ondersteunen. De bruikbaarheid is getest door het afnemen van semigestructureerde interviews met N-ONM operators, nadat zij N-ONM taken hadden uitgevoerd in de simulatieomgeving. Het effect van de UI's is getest met behulp van 'within-subject' experimenten voor het meten van statistisch significante verschillen in het SA, de taakprestaties en de werklast van operators. Deze testen maakten gebruik van data verkregen tijdens de taakuitvoering in de simulatieomgeving. Deze data bestond uit gegevens die door de simulatiesoftware opgeslagen werden, zoals alle acties uitgevoerd door de operators, en gegevens geregistreerd door de testleider en observant, zoals de inhoud van communicatie. De resultaten van het testen van de bruikbaarheid en het effect van de UI zijn gebruikt om te valideren of de IE-aanpak helpt om de tekortkomingen van de huidige systemen op te lossen. Logische gevolgtrekking is gebruikt om te valideren of IE bijdraagt aan het verbeteren van SA-support. Als uit het testen van de prototypes blijkt dat IE een positief effect heeft op SA-support, dan gaan we er van uit dat de onderliggende concepten en de IE-aanpak daarvoor ook geschikt zijn.

Resultaten

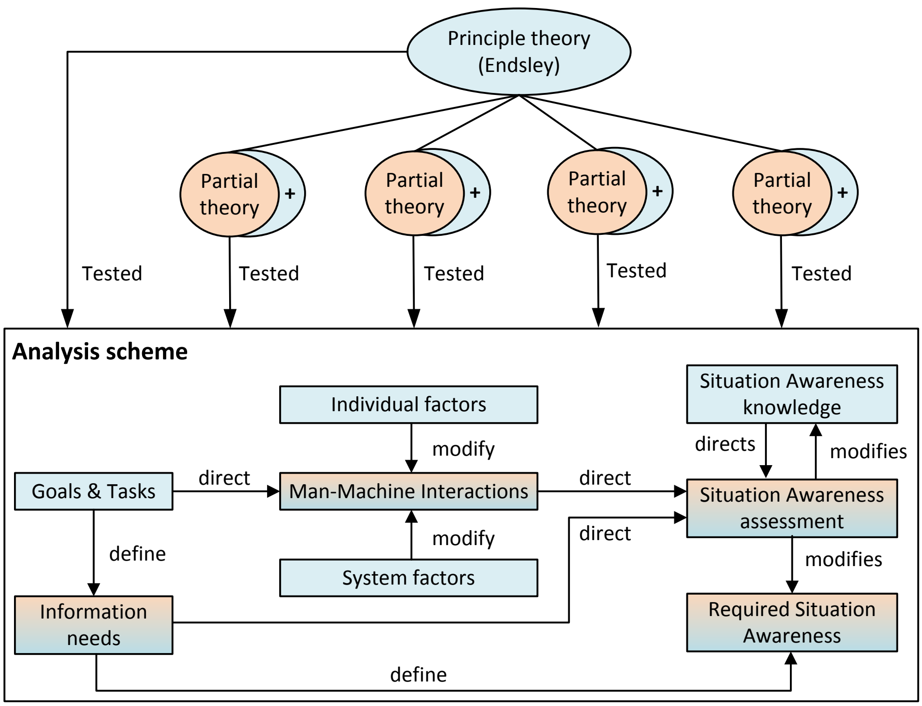
Een analyseschema voor een holistische analyse van het vereiste situatiebewustzijn

Onze literatuurstudie liet zien dat het bij een studie naar SA in het geval van complexe informatiesystemen nodig is om een onderscheid te maken tussen informatie die onderdeel moet zijn van een operator zijn SA en de overige benodigde informatie. Bestaande theorieën maken dit onderscheid echter niet. In dit onderzoek stellen wij de volgende definities voor:

> *Informatiebehoefte is alle informatie die nodig is om de operator zijn doelen succesvol te laten behalen.*

> *Vereist situatiebewustzijn is die informatie over de dynamische omgeving waarvan het essentieel is dat de operator deze mentaal paraat heeft tijdens zijn taakuitvoering, waarbij de noodzaak en relevantie afhangen van de informatiebehoefte en de interactie tussen doelen, taken, individuele factoren en systeemfactoren.*

In samenhang met deze definities hebben we ter ondersteuning van een holistische analyse van SA een analyseschema ontwikkeld. Dit analyseschema is afgeleid van bestaande theorieën door middel van kritische synthese, zie Figuur 1.



Figuur 1 Het proces van combineren van bestaande geteste theorieën in een analyseschema voor het holistisch analyseren van situatiebewustzijn

Een aanpak voor het identificeren van tekortkomingen in SA-support

Veelgebruikte methodes voor het identificeren van tekortkomingen in SA-support zijn (i) analyse van ongevalsrapportages, (ii) meten van het SA van operators in een simulatieomgeving, en (iii) observationeel onderzoek. Ongevalsrapportages en een simulatieomgeving zijn niet altijd beschikbaar. Dit was ook het geval in onze N-ONM casestudie. Verscheiden onderzoekers geven aan dat observationeel onderzoek niet voldoende accuraat is voor het meten van SA. In dit onderzoek hebben we het van bestaande theorieën afgeleide analyseschema gebruikt om een alternatieve methode te ontwikkelen voor het identificeren van tekortkomingen in SA support. We gebruikten daarbij een combinatie van cognitieve taakanalyse en observationeel onderzoek om alle aspecten van het analyse schema te kunnen onderzoeken. Onze aanpak was gebaseerd op syntactische-semantische verwerking van de resulterende gegevens. Deze voorgestelde aanpak hebben we toegepast in onze N-ONM casestudie. In totaal hebben we 30 tekortkomingen van de ondersteuning van SA geïdentificeerd, waarvan er 23 betrekking hebben op hoe de gebruikersinterfaces de operators ondersteunen met informatieverwerking.

Deze tekortkomingen zijn geclusterd in vier hoofdgroepen:

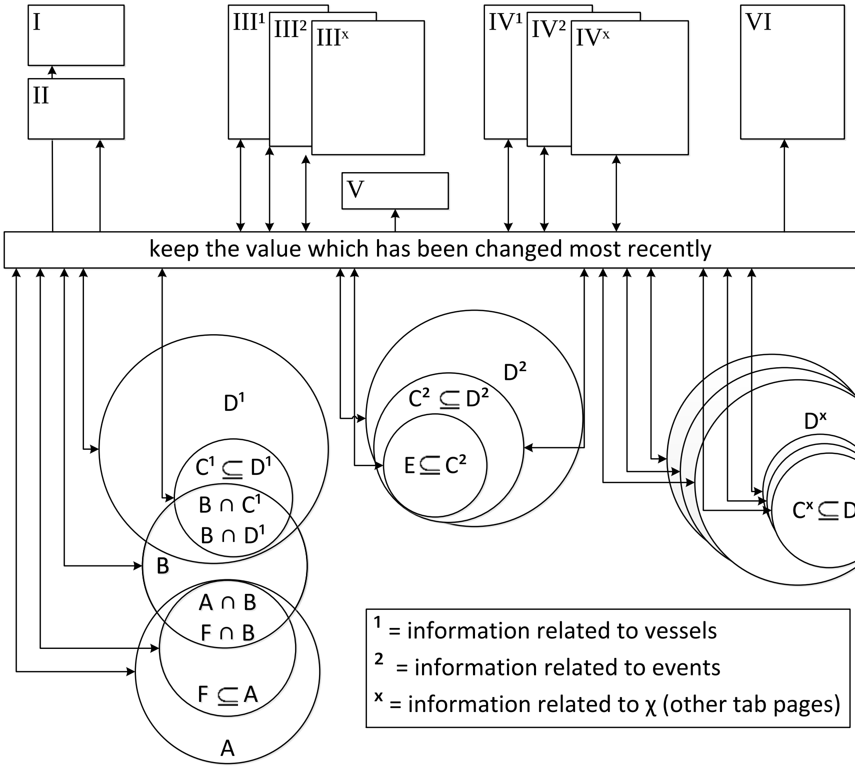
- D.1. De kwaliteit van de informatie wordt door de operators als onvoldoende ervaren
- D.2. Operators krijgen lastig toegang tot benodigde informatie
- D.3. De gebruikte informatievisualisatie zorgt ervoor dat operators moeite hebben om een groot verkeersmanagementgebied te overzien
- D.4. Operators voeren niet alle relevante acties uit

Definiëren van gebruikersinterface concepten ten behoeve van het oplossen van de vier groepen tekortkomingen

UCD bleek nuttig voor het identificeren van de informatiebehoefte en voor het vormgeven van de UI's. UCD bood echter onvoldoende hulp bij het ontwerpen van informatievisualisatie die operators ondersteunt in informatieverwerking bij grote hoeveelheden informatie. We benaderden de tekortkomingen van systemen met betrekking tot ondersteuning van informatieverwerking daarom vanuit het oogpunt van IE. Dit hielp bij het ontwikkelen van de volgende drie UI-concepten:

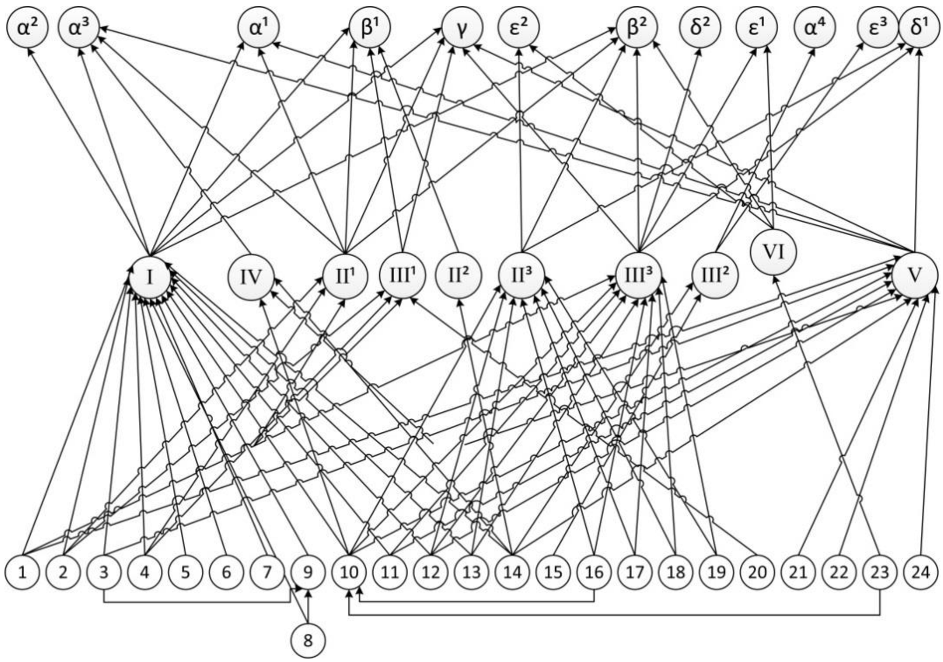
- *Een **coherente gebruikersinterface** is een logische, consistente, ordelijke en harmonieuze interface. Als er meerdere gerelateerde interfaces zijn, dan vormen ze een samenhangend geheel.*
- *Een **geïntegreerde gebruikersinterface** maakt gebruik van informatie-fusie en interacties tussen meerdere gebruikersinterfaces. Gerelateerde informatie-elementen zijn geïntegreerd ter ondersteuning van specifieke taken die zijn toegewezen aan de rol van de operator.*
- *Een **context-afhankelijke aanpasbare gebruikersinterface** ontvangt contextinformatie, beoordeelt de gevolgen van context, en past de inhoud en compositie van de gebruikersinterface aan de hand daarvan aan om zo goed mogelijk de relevante taken in de gegeven context te ondersteunen.*

De beginselen van de verzamelingenleer zijn gebruikt voor het definiëren van de coherente gebruikersinterface. Dit maakte het mogelijk om informatie-elementen te relateren aan onderdelen van het systeem, zie Figuur 2. Bij het ontwerpen van de geïntegreerde gebruikersinterface richtten we ons op het verminderen van redundante, ongeordende en versnipperde brokken informatie. Hiervoor pasten we de beginselen van de verzamelingenleer en grafentheorie toe. Deze beginselen stelden ons in staat om de logische relaties tussen informatie-elementen en de functionele interactie tussen informatieschermen te specificeren. Een voorbeeld van een schema dat is gebruikt bij het ontwerpen van een geïntegreerde gebruikersinterface is weergegeven in Figuur 3. Het ontwerpen van een context-afhankelijke aanpasbare gebruikersinterface vereist om het geheel aan semantische relaties tussen informatie-elementen vast te leggen. Daarmee kunnen condities gedefinieerd worden die relevant zijn voor context-afhankelijke besluitvorming. We gebruikten semantisch netwerken om zowel de semantische relaties als de besluitvormings- voorwaarden vast te leggen, zie Figuur 4.

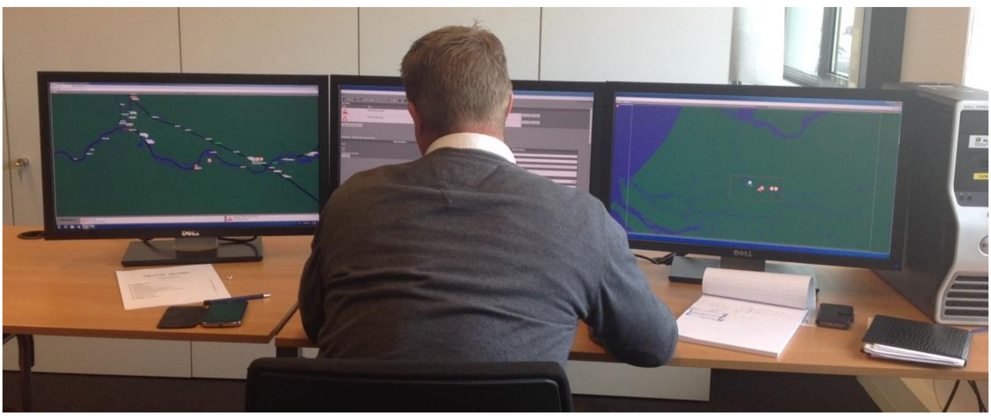


Figuur 2 Coherente gebruikersinterfacespecificatie gebaseerd op de verzamelingenleer (de cirkels representeren de informatie verzamelingen, de rechthoeken de informatieschermen)

We implementeerden de ontwikkelde concepten in een N-ONM werkplek simulator om het nut van de concepten in de praktijk te evalueren. Eerst pasten we UCD methodes toe om te bepalen welke informatiebehoeftes N-ONM operators hebben bij het behalen van hun doelen. En om de UI concepten vorm te geven. Daarna pasten we de drie IE-gebaseerde concepten toe op dit ontwerp. Ten slotte ontwikkelden we een N-ONM werkpleksimulator, waarin we de drie concepten implementeerden om hun haalbaarheid en toepasbaarheid aan te tonen. (Figuur 5).



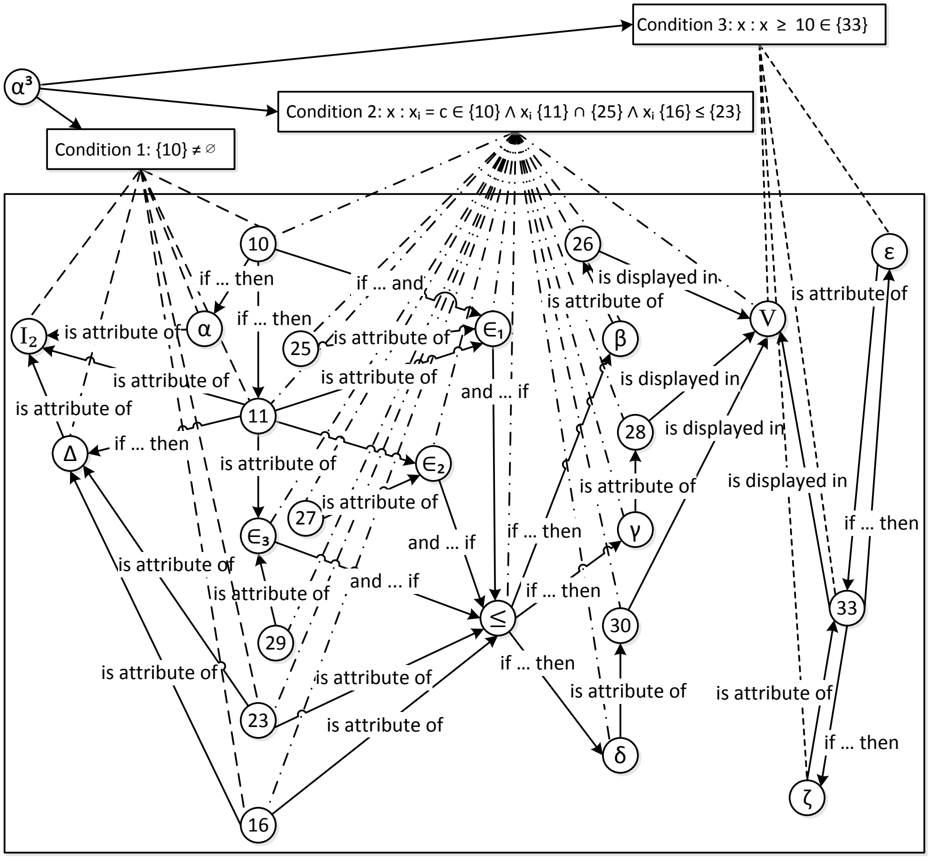
Figuur 3 Contentintegratiediagram (CIG) van de ontwikkelde geïntegreerde gebruikersinterface voor N-ONM taken



Figuur 5 N-ONM werkpleksimulator met daarop de geïntegreerde gebruikersinterface

Valideren van informatie-engineering als een middel om SA support te verbeteren

Bruikbaarheidstests toonden aan dat de voorgestelde IE-aanpak een positief effect heeft op de effectiviteit, efficiëntie en gebruikerstevredenheid. De coherente UI bood onvoldoende ondersteuning voor het beoordelen van de verkeerssituatie en voor het bepalen van de impact van beperkingen. De



Figuur 4 Context-afhankelijkheidsdiagram (CDG) van een context-afhankelijke aanpasbare gebruikersinterface voor N-ONM taken

geïntegreerde UI bood betere ondersteuning dan de coherente UI. De context-afhankelijke aanpasbare UI werd beoordeeld als de UI welke de N-ONM taken het beste ondersteunde.

Beoordeling van de impact van de UI-prototypes op het SA, de taakuitvoering en de werklast van de operators bevestigde de uitkomsten van de bruikbaarheidstudie. Operators waren bij het gebruik van een coherente UI (i) langzamer in het opdoen van SA, (ii) langzamer in communicatie met belangrijke stakeholders, en (iii) de kans dat operators taken uitvoerden in de vereiste volgorde was kleiner bij het gebruik van een coherent UI dan bij het gebruik van een geïntegreerde UI of context-afhankelijke aanpasbare UI. Een context-afhankelijke aanpasbare UI bood de beste ondersteuning voor het beantwoorden van vragen van schippers die gerelateerd waren aan de toekomstige staat van de verkeersmanagementomgeving.

Het toepassen van de voorgestelde IE-aanpak hielp bij het aanpakken van tien van de 23 geïdentificeerde tekortkomingen met betrekking tot menselijke informatieverwerking. De bruikbaarheidstests en evaluatie van de impact van de UI-concepten liet zien dat IE een positief effect had op acht van deze tien tekortkomingen. Op basis van logische gevolgtrekking concluderen we dat de voorgestelde IE-aanpak ontwerpers ondersteunt in het oplossen van tekortkomingen van SA support.

Conclusies

Ter conclusie van dit onderzoek en de resultaten zijn de volgende stellingen geformuleerd:

1. Een holistisch begrip van de invloeden van mens - machine interacties is noodzakelijk bij het onderzoeken van situatiebewustzijn van operators werkzaam met complexe informatiesystemen.
2. Een analyseschema dat de informatiebehoeften onderscheidt van het vereiste situatiebewustzijn, verhoogt de efficiëntie van het onderzoeken van tekortkomingen van ondersteuning voor situatiebewustzijn door complex nautisch verkeersmanagement systemen.
3. De informatie-engineering aanpak die wordt voorgesteld voor het ontwerpen van coherente, geïntegreerde en context-afhankelijke aanpasbare gebruikersinterfaces ondersteunt niet alleen ontwerpers in het ontwerpen van informatievisualisatie, maar systematiseert ook het proces van de ontwikkeling van interface inhoud.
4. De specificatie van syntactische en semantische relaties tussen informatie-elementen vergroot het vermogen van nautische verkeersmanagement systemen om het situatiebewustzijn en de taakprestaties van operators te ondersteunen.

Appendix I

APPENDIX I

SUBTASKS AND ACTIVITIES OF N-ONM

This table shows an overview of activities per sub-task as defined for N-ONM, with the information processing level as defined by Rasmussen (1986)[1] . Table over multiple pages.

Tasks	Activities	Information processing
Locate / identify shipping	Received mandatory notification of vessel within the network	Skill-based
	Update navigational plan data (if necessary)	Skill-based
	Advise chief operator on merging or splitting sectors	Rule-based
Follow shipping	Obtain current image of the (possible) obstructions	Skill-based
	Obtain up-to-date image of the fairway markers (including lighting and buoys)	Skill-based
	Request vessel label (if necessary)	Skill-based
	Interpret traffic image within the network	Rule-based
Observe network (Continues on next page)	Observe Planning Area	Skill-based
	Analyze volume of traffic	Rule-based
	Determine availability fairway / objects	Rule-based
	Forecast (expected) use of locks	Rule-based
	Forecast (expected) use of bridges	Rule-based
	Forecast (expected) use of anchorage grounds	Rule-based
	Forecast (expected) traffic image planning area (crowdedness, use, in time, …)	Rule-based
	Observe status of lock and bridge openings	Skill-based
	Observe state of fairways (Depths, shallow water) (incl. ports and terminals)	Skill-based

[1] Rasmussen, J. (1986) Information processing and human-machine interaction: an approach to cognitive engineering. North-Holland, New York.

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Tasks	Activities	Information processing
Observe network (Continuation from previous page)	Observe flow rate, flow direction, flow information and water levels	Skill-based
	Observe operational state buoys, beacons and other navigation tools	Skill-based
	Observe meteorological and hydrological conditions	Skill-based
	Determine proximity to possible barriers in the fairway	Rule-based
	Determine possible risk situations	Rule-based
	Observe the reported restriction	Skill-based
	Register the reported constraint	Skill-based
	Determine availability of objects (failures, damage)	Rule-based
	Determine effects (impact) of network constraints	Rule-based
Register information	Register of reported cargo, travel and crew information (if necessary)	Skill-based
	Register treatment status of a vessel (if necessary)	Skill-based
Provide traffic information	Provide current traffic information/advice within the network	Rule-based
	Inform about the expected traffic image within the network	Skill-based
	Inform about meteorological and hydrological conditions	Skill-based
	Inform about availability of fairway/objects	Skill-based
	Communicate with mobile traffic control	Skill-based
Provide information in cases of restrictions	Actively provide information on affected traffic measures within the network	Skill-based
	Provide current traffic information/advice in cases of restrictions	Rule-based
	Provide information/advice in the sector on alternative routes	Rule-based
	Provide information/advice in the sector on travel information of alternative routes	Rule-based
	Warn/Consult other organizations and objects	Rule-based

Continuation from previous page

Tasks	Activities	Information processing
Take active actions for incident management	Provide traffic information in cases of restrictions (incidents) within the network	Rule-based
	Coordinate usage resources (including patrol vessels)	Rule-based
Determine impact (planned restrictions)	Contribute to scenario / plan of action	Skill-based
	Receive scenario / plan of action planned restrictions	Skill-based
	Check availability fairway/items as mentioned in scenario / plan of action	Rule-based
	Check availability anchorage grounds / waiting areas as mentioned in scenario / plan of action	Rule-based
	Review of traffic measures proposed in scenario / plan of action	Rule-based
	Determine scope and nature of the planned restriction	Rule-based
	Determine the impact of restrictions on volume of traffic	Rule-based
	Forecast (expected) use locks	Rule-based
	Forecast (expected) use bridges	Rule-based
	Forecast (expected) use anchorage grounds	Rule-based
	Forecast (expected) traffic image within the network (crowdedness, use, in time, …)	Rule-based
	Assess the need for additional traffic measures	Knowledge-based
Determine impact (unplanned restrictions) (Continues on next page)	Receive notification unplanned restrictions	Skill-based
	Assess necessity setting traffic measure	Rule-based
	Assess necessity escalation to national level	Rule-based
	Determine the scope and nature of the restriction	Rule-based
	Determine the impact of restrictions on volume of traffic	Rule-based
	Assess the impact of traffic measures	Rule-based
	Forecast (expected) use locks	Rule-based
	Forecast (expected) use bridges	Rule-based
	Forecast (expected) use anchorage grounds	Rule-based

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Tasks	Activities	Information processing
Determine impact (unplanned restrictions) (Continuation from previous page)	Forecast (expected) traffic image within the network (crowdedness, use, in time, …)	Rule-based
Prepare traffic measure (unplanned restrictions)	Determine traffic measures on the basis of the catalogue of measures	Rule-based
	Assess the need for additional traffic measures	Knowledge-based
	Align traffic measures with ongoing maintenance at neighboring waterways and objects	Rule-based
	Align traffic measures with other waterway authorities and enforcement services	Rule-based
	Inform / escalate to national level	Rule-based
	Align with own management and incident organization	Rule-based
	Communicate with mobile traffic control	Skill-based
Take actions to remedy limitations and to effect traffic measures	Classify restriction (shipping incident)	Rule-based
	Classify constraint (malfunction/damage)	Rule-based
	Alert emergency services	Rule-based
	Enable third party (for remedying malfunction/damage)	Rule-based
	Inform about set redirection (obstruction)	Skill-based
	Inform about anchorage grounds and waiting areas	Skill-based
Set traffic measures (Continues on next page)	Set temporary adjustment of fairway markers	Rule-based
	Set temporary adjustment of traffic rules (speed, run-off bans, one-way traffic, …)	Rule-based
	Set temporary adjustment of control regime (locks, bridges)	Rule-based
	Set up specific traffic control (by central or patrol vessel)	Rule-based

Continuation from previous page

Tasks	Activities	Information processing
Set traffic measures (Continuation from previous page)	Set up alternate navigation route	Rule-based
	Inform about availability fairway / objects	Skill-based
	Inform about availability anchorage grounds / waiting areas	Skill-based
	Provide up-to-date information on route-travel times	Skill-based
	Announce any temporary adjustment to fairway marking	Rule-based
	Announce temporary adjustment of traffic rules (speed, run-off bans, one-way traffic, …)	Rule-based
	Announce temporary adjustment of control regime (locks, bridges)	Rule-based
	Announce specific traffic control (by central or patrol vessel)	Rule-based
	Announce alternate navigation route	Rule-based
	Internally inform VTS-, lock-, and bridge operators and patrol vessels	Rule-based
	Direct patrol vessels	Knowledge-based
Lift traffic measures (Continues on next page)	Lift temporary adjustment to fairway marking	Rule-based
	Lift temporary adjustment of traffic rules (speed, run-off bans, one-way traffic, …)	Rule-based
	Lift temporary adjustment of control regime (locks, bridges)	Rule-based
	Lift specific traffic control (by central or patrol vessel)	Rule-based
	Lift alternate navigation route	Rule-based
	Announce lifting up temporary adjustment to fairway marking	Rule-based
	Announce lifting up temporary adjustment of traffic rules (speed, run-off bans, one-way traffic, …)	Rule-based
	Announce lifting up temporary adjustment of control regime (locks, bridges)	Rule-based

Continuation from previous page

Tasks	Activities	Information processing
Lift traffic measures (Continuation from previous page)	Announce lifting up specific traffic control (by central or patrol vessel)	Rule-based
	Announce lifting up alternate navigation route	Rule-based
Register information	Register restrictions	Skill-based
	Register set traffic measures	Skill-based

APPENDIX II

ERROR PROBABILITY AND MENTAL WORKLOAD OF COGNITIVE TASKS

This table gives an overview of the cognitive tasks of N-ONM and how the operators rated these tasks in terms of error probability and mental workload on a scale 1 (very low) – 5 (very high). Table continues on next page.

	Error probability		**Mental workload**	
	Median	SD (σ)	Median	SD (σ)
Follow shipping				
Interpret traffic image within the network	2	1,12	3	1,16
Observe network				
Analyze volume of traffic	2	0,95	2	1,02
Determine availability fairway / objects	1	0,98	2	1,06
Determine proximity to possible barriers in the fairway	2	0,86	2	1,09
Determine possible risk situations	3	1,00	3	1,37
Determine availability of objects (failures, damage)	1	0,98	2	0,78
Determine effects (impact) of network constraints	2	0,86	3	0,99
Provide traffic information				
Provide current traffic information/advice within the network	2	0,78	2	0,83
Provide information in cases of restrictions				
Provide current traffic information/advice in cases of restrictions	2	1,01	2	0,93

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	Error probability		Mental workload	
	Median	SD (σ)	Median	SD (σ)
Determine impact (planned restrictions)				
Review of traffic measures proposed in scenario / plan of action	2	0,79	2	1,03
Determine scope and nature of the planned restriction	2	0,82	2	1,05
Determine the impact of restrictions on volume of traffic	2	0,67	2	1,12
Assess the need for additional traffic measures	2	0,97	2.5	1.31
Determine impact (unplanned restrictions)				
Assess necessity setting traffic measure	2	0,77	3	0.92
Assess necessity escalation to national level	3	0,67	3	0.88
Determine the scope and nature of the restriction	3	0,60	3	0.66
Determine the impact of restrictions on volume of traffic	2	0,76	2	0.77
Assess the impact of traffic measures	2	0,74	3	0.96
Prepare traffic measure (unplanned restrictions)				
Determine traffic measures on the basis of the catalogue of measures	2	0,79	2	0.88
Coordinate usage resources (including patrol vessels)	2	0,77	2.5	0.91
Assess the need for additional traffic measures	2	0,65	2	0.83
Take actions to remedy limitations and to effect traffic measures				
Classify restriction (shipping incident)	2	0,90	3	0.87
Classify constraint (malfunction/damage)	2	1,00	2	0.90

APPENDIX III

INFORMATION NEEDS OF N-ONM

This table shows an overview of N-ONM information needs and their ratings, on a scale 1 (very low) – 5 (very high). Table over multiple pages.

	Importance to access information		Importance to have as part of operators' SA	
	Median	SD (σ)	Median	SD (σ)
Waterway information				
Waterway network overview	4	1,65	4	1,61
Waterway ground structures	3	1,4	2	1,24
Fairway positions	2	1,61	2	1,30
Waterway capacity	3	1,43	3	1,26
Waterway shipping intensity	4	1,63	3	1,34
Position wrecks	3	1,73	3	1,51
Waterway banks information				
Location waterway banks	4	1,44	3	1,07
Position roads near waterway	4	1,19	3	1,04
Names roads near waterway	4	1,34	3	1,04
Information about roads near waterway (speed limit, one-way traffic)	3	1,38	1	1,32
Position operating bases emergency services	3	1,54	3	1,28
Position boarding areas emergency services	4	1,36	3	1,19
Companies near waterway	4	1,15	3	0,90
Waterway elements information (continues on next page)				
Expected position fairway marking	3	1,23	3	1,01

Continuation from previous page

	Importance to access information		Importance to have as part of operators' SA	
	Median	SD (σ)	Median	SD (σ)
Current position fairway marking	3	1,42	2	1,24
Type fairway marking	3	1,36	2	1,19
Identity fairway marking	3	1,19	2	1,23
Position buoys	3	1,16	2	1,08
Status buoys	3	1,51	2	1,29
Status beacons	3	1,52	2	1,34
Status lighting	3	1,69	2	1,36
Status other navigation aids	3	1,72	2	1,41
Position DSP	2	1,96	3	1,59
Message on DSP	2	1,97	3	1,59
Name anchorage grounds	3	1,6	3	1,12
Position anchorage grounds	3	1,5	3	1,06
Availability anchorage grounds	4	1,27	3	1,05
Objects information				
Location objects	4	1,41	3	1,34
Control status objects	4	1,38	3	1,15
Capacity objects	4	1,36	3	1,30
Shipping intensity near objects	4	1,4	3	1,36
Anticipated intensity near objects	4	1,74	2	1,55
Anticipated waiting time objects	3	1,53	3	1,40
Overview planned lock turnings / bridge openings	3	1,24	3	1,31
Status signs for waterway user bridge / lock	3	1,48	2	1,41
Status moving parts bridge / lock	3	1,46	2	1,22
Hydrological / meteorology information (continues on next page)				
Water level	3	1,53	3	1,40
Current speed	4	1,5	3	1,29
Current direction	4	1,62	3	1,48

Continuation from previous page

	Importance to access information		Importance to have as part of operators' SA	
	Median	SD (σ)	Median	SD (σ)
Position hydro / meteo sensors	3	1,62	2	1,48
Wave height	3	1,69	2	1,56
Wave period	3	1,76	2	1,64
Wave direction	2	1,77	2	1,72
Anticipated time low and high tide	3	1,31	2	1,38
Wind direction	4	1,5	3	1,37
Wind speed	4	1,5	3	1,37
Blasts	3	1,55	3	1,44
Sight distance	4	1,44	2	1,55
Vessel information (continues on next page)				
Relative amount of vessels in the N-ONM area	4	1,36	3	1,21
Radar image vessels	3	1,69	3	1,39
Coordinates current position vessels	4	1,59	3	1,43
Name vessel	4	1,36	3	1,49
ENI-number	4	1,11	2	1,53
Nationality vessels	4	1,47	1,5	1,44
Treatment status vessels	3	1,49	3	1,44
Safety signs vessels	4	1,26	3	1,27
Estimated time of departure vessels	4	1,21	3	1,47
Names route points vessels	3	1,85	2	1,70
Time route points vessels	3	1,94	2	1,77
Estimated time of arrival vessels	3	1,35	2,5	1,39
Distance between vessel and fixed point	3	1,69	1	1,76
Sounding between vessel and fixed point	3	1,88	1	1,80

Continuation from previous page

	Importance to access information		Importance to have as part of operators' SA	
	Median	SD (σ)	Median	SD (σ)
Current vessel speed	3	1,61	2	1,25
Vessel direction	3	1,69	1,5	1,32
Indication lost track	2	1,91	1	1,61
Headway between two vessels	2	1,76	1,5	1,28
Sounding between two vessels	2	1,79	1	1,35
Information cameras				
Camera images waterway	4	1,39	3	1,34
Camera locations	4	1,50	3	1,51
Camera names	4	1,66	3	1,79
Camera types	4	1,86	1	1,69
Status cameras	2	1,86	3	1,64
Information restrictions				
Position restricted availability waterways	4	1,27	3,5	1,22
Type restriction availability waterway	4	1,32	3,5	1,48
Explanation restriction availability waterway	4	1,46	3	1,59
Forecast duration restrictions	4	1,36	3	1,41
Position malfunctioning objects	4	1,71	4	1,22
Type malfunctioning objects	4	1,42	3	1,47
Explanation malfunctioning objects	4	1,25	3	1,50
Forecast duration malfunctioning objects	3,5	1,38	3	1,39
Traffic measures information				
Scrips planned restrictions	4	1,82	3	1,24
Control scenarios	4	1,79	3	1,30
Measures taken	3,5	1,71	3	1,28
Explanation measures taken	3	1,61	3	1,30
Forecast duration measures taken	3	1,61	3	1,31

Continuation from previous page

	Importance to access information		Importance to have as part of operators' SA	
	Median	SD (σ)	Median	SD (σ)
Communication information				
Content notices to skippers	4	1,24	3	1,38
VHP channel of call	4,5	1,64	4	1,36
Estimated location of VHF call	4	1,78	3	1,62
ATIS-code vessels	4	1,46	2,5	1,51
Phone numbers received call	4	1,71	3	1,53
Phone numbers emergency services	5	1,71	4	1,35

APPENDIX IV

OVERVIEW OF SYNTACTIC-SEMANTIC PROCESSING STEP 1 - 4

This appendix shows an overview of the raw data of our case study which was related to sources of SA errors. Since the sessions were held in Dutch, the raw data indicators are in Dutch as well. Context information was used to formulate the related problem per syntactic group.

Sources used:

Sources	Abbreviation
Task analysis session with 10 operators	T1
Task analysis session with 12 operators	T2
Information needs session with 10 operators	I1
Information needs session with 12 operators	I2
Knowledge audit session with 10 operators	K1
Knowledge audit session with 12 operators	K2
Simulation interview session with 10 operators	S1
Simulation interview session with 12 operators	S2
Observation questionnaires filled in by observed operators	OQ1 - OQ6
Observer notes	ON1 - ON6
Observer checklist	OC1 - OC6

Results of syntactic-semantic processing step 1 – 4, table over multiple pages.

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
External processes influencing ONM tasks take long	Processen ook te versnellen. Duurt vaak ook nog wel een heleboel tijd	Some processes take long	Some external processes which influence ONM tasks, like solving malfunction of sluice or including data about new objects in information systems, take long.	T1(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
ONM operators do not follow a uniform working method	Niet uniform. Verschillende meningen. Ligt niet vast. Die het dan weer anders doen. Altijd zoveel verschillen. Gaat het anders als. Veel verschillen . Doen andere dingen. Een mening over. Op een andere manier doen.	ONM operators do not follow a uniform working method	There are no uniform working method instructions. Different regions work differently. Not all tasks have clear instructions. And when instructions are available, not all operators follow these instructions.	T1(2), K1(2)
	Weet niet hoe. Meerdere dingen kunnen. Andere taak, dan een draaiboek, maar bij (taak) toch wel een ding . Zit er wel altijd naast. Grijs. Varieert. Ervaring. Loop der tijd. Inschatten. Ligt niet vast. Afwegen. Afbakenen. Gradaties. Helder. Zwart / Wit. Tussenin. werkafspraken niet weten. Communicatie verschillen. zo aanpakken.	Un-structured work process, certain tasks require personal consider-ations based on experience	Some tasks, like handling of incidents or unplanned obstruction of waterways or communication with others, do not have a clear work process. Operators have to improvise and rely on their own experience.	T1(1), K1(4), S1(1)
Collabora-ting stakeholders do not follow a uniform working method	Ook standaardisatie bij. In Noord Holland … en in Utrecht …. In Oost Nederaldn die manier. Belt ipv marifoon. Melden niet op juiste locatie. Anders georganiseerd. Ook anders.	Collabora-ting stakeholders do not follow a uniform working method	The different roles which need to collaborate with ONM operators do not follow a uniform working method and use different systems. This results in different ways of communication and collaboration. Skippers call by phone instead of contact through VHF.	K1(1), S1(1), ON(1), OQ1(1), S2(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
ONM requires to pursue multiple tasks simultaneously	Vaak afgeleid door zaken die er lopen. Achter raakt. Heel veel zaken naast elkaar. Alles komt op jou aan. Verkeer blijft doorgaan. Je bent bezig met… Andere dingen laten lopen. Afweging maken. Tegelijkertijd optreden. Collega's bijspringen. Verschillende locaties. Twee plekken. Twee calamiteiten. Dat is druk.	Multiple tasks simultaneously	Operators in traffic management control environments pursue multiple goals simultaneously. To do so, they need to carry out multiple tasks, which require time-constrained decisions and actions. They are responsible for safe water levels, safe traffic situations and efficient traffic flows.	T1(2), K1(1), OQ1(1), T2(1)
	Schepen die zich tegelijkertijd melden, elkaar niet horen. Tegelijk binnenkomen. Door elkaar roepen.	Simultaneous calls from different skippers	Different ships sometimes contact ONM operator simultaneously. By phone and/or by VHF. They do not hear each other. The operator has to understand, distinguish and respond to both.	OQ1(2), OQ2(1)
	Prioriteiten stellen. Lastig prioriteren.	Difficult to prioritize incidents.	If more than one incident occur at the same moment, it is difficult for operators to prioritize.	T2(1)
	Twee grote calamiteiten. Lastig te regelen.	Difficult to control multiple incidents.	Difficult to control incidents which take place simultaneously.	T2(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
Current information presentation puts high demands on operator's ability to keep overview of a large area of control (Continues on next page)	Ligt aan programma's waar me mee werkt, hoe je overzicht kan houden. Zo ver uitzoom, wordt het één grote stip. Grote beperking Narcis. Presentatie op werkplek.	System insufficiently supports overview	ONM operators need to focus on corridor management, requiring a general overview of a large area. They currently use systems designed for other nautical tasks, which focus on local traffic management. These systems are designed to provide detailed information of a certain location and are less suitable to provide an overview of the larger area.	T1(2), T2(1)
	Niet continu zichtbaar	Information not continuously visible	Difficult to maintain overview because not all information is continuously visible.	OQ1(0,5), OQ2(0,5), OQ3(1)
	Veel informatie.	Large amount of information	Difficult to maintain overview because operator needs to monitor large amount of information.	OQ1(0,5), OQ2(1), OQ3(1)
	Areaal best wel groot. Waar zezitten. Wil je niet op moeten zoeken. Moet je gewoon zo zien.	Difficult to monitor location of RWS boats	In current systems, due to large area of control, it is difficult to monitor where the RWS boats are.	I2(1)
	Goed overzichts-vermogen moet hebben.	Ability to keep overview	The large area of control, multiple tasks and the use of systems which insufficiently supports overview together result in high demands on the operator's ability to keep overview.	T1,(1), T2(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
Current information presentation puts high demands on operator's ability to keep overview of a large area of control (Continuation of previous page, continues on next page)	Die moet ik niet hebben. Moet een ander hebben. Verkeerde schipper. Ander schip.	Confusion, mix up ships.	Operators sometimes want to contact ship A, but mix up ships and by accident contact ship B.	T1(1)
	Je zit hier en er gebeurt daar wat. Er bovenop. Zit wel in je hol. Op traject anders dan hier. Hoort het te laat. Wat daar gebeurt. Iemand ter plaatse. Geen oogjes op traject.	Remote control, awareness based on indirect information.	Operator has no direct view on the area of control. Operator needs to rely on information from systems and others to obtain a mental picture of the situation. No camera images of large part of corridor.	T1(3), I1(2), K2(2),
	Meerdere namen die op meerdere locaties voorkomen. Er zijn meer sluizen die Bernardsluis heten.	Identic names for different objects	Different objects at different locations in the area of control have an identic name. For instance two sluices or two ships have the same name.	S1(1)
	Met viewers gebouwd. Alleen maar zien.	GIS works as viewer, not possible to add information	Current GIS systems are viewers. Operators can search for information, but are not able to add information. They therefore do not support operators to store mentally available information.	T2(1)
	Twee grote calamiteiten. Lastig uit elkaar te houden.	Difficult to keep apart incidents	Difficult to keep apart incidents which take place simultaneously.	T2(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
Current information presentation puts high demands on operator's ability to keep overview of a large area of control (Continuation of previous page)	Fout interpreteert. Gemakkelijk over denken. Te groots. Te spannend.	Misinterpret severity of incident	Misinterpretation of severity of situation resulting in unnecessary actions. Play down or exaggerate incident.	S2(3)
	Snel tevreden met sussende woorden.	Overreliance on judgement of others	Misinterpretation of situation due to overreliance on judgement of others, especially relevant when less experienced.	S2(1)
Some information is subject to change	Net buiten gebied. Ineens daar. Hoe groot het gebied. Een grens aan de informatie. Bij Duitsland zal een grens zijn. Heb je het niet in beeld. Buiten je grens kijken.	No information until object enters own area of control.	The operator is responsible for a certain area and has information about this area. Ships, water and dangerous influences like smoke or chemicals however can come from outside this area and at a certain moment enter the area. Information from outside the area is not available. If you increase the area, there will always be a new boundary.	T1(2)
	Veranderd.	Information subject to change	Some information is subject to change. Company names for instance change over time. There is no signal indicating this changed, but it for instance is noticed in communication with skippers.	I1(1)
	Dynamisch. Blijft niet staan de hele dag.	Some information is highly dynamic	Some information is highly dynamic, changes over the day. Such as weather conditions, water levels and depth.	I1(1), ON(2)

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Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
ONM operators are exposed to stressful situations	Stress. Niet weet hoe. Risicovolle situatie. Meerdere dingen bij kunnen komen. Mentale belasting. Fikse doorstroming van je bloed. Gaat het wel goed. Mee maken.. Sodeju. Mij allemaal overkomen. Trek je niet. Zoveel voorbij zien komen. Krijgt teveel over je heen. Voor thuis geweest. Een douw van gehad.	Stress due to severe incidents increases mental workload	Operators are involved in severe incidents, with high impact on stakeholders, like injuries or dead. This causes stress. During an incident, this increases the mental workload. After an incident, the stress sometimes remains. The time it takes to deal with shocking experiences differs among operators.	T1(5)
	Een bepaalde tijd. Tot aan dat je werkelijke weet. Wat er aan de hand is. In de tussentijd. Bepaalde tijd van onzekerheid. Wachten. Pas na twee minuten. Duurt heel lang. Wilt eigenlijk snel handelen.	Moment of uncertainty between issue report and mental overview is mentally demanding.	There is always a moment of uncertainty between an issue report and the moment of which the operator can have a mental overview of the situation. An issue comes up suddenly, and the operator needs to search for and wait for information. It for instance often is not straight away clear if there are injured people on board. This uncertainty increases mental workload.	T1(2)
	Neemt niet op. Mentale belasting.	Mental workload difficulty to reach informant	Mental workload when not able to reach the people necessary to obtain information.	K2(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
ONM actions have far-reaching consequences	Hoop impact. Drie keer nadenken. Impact groot. Mentale belasting om beslissing te nemen. Wel kunnen slapen. Had ik maar.	Far-reaching consequences of errors increases mental workload	Operator's actions can have high impact on stakeholders, like injuries or dead. This increases the mental workload.	T1(1), K1(1)
	Ingrijpende dingen. Terughoudend. Economisch verhaal.	Far reaching consequence of actions	Actions taken by operators can have far reaching consequences for stakeholders. Like closing a waterway for skippers has a large economic impact.	T2(1)
ONM by essence deals with unforeseen and unplanned issues	BAF. Steekt nu de kop op. Er ontstaat iets. Gebeurt iets. Moet het nu regelen. Op voorbereiden. Ad-hoc. Meteen van huppakee. Onverwacht. Snel schakelen. Ineens. Boem.	Unforeseen issues can be very sudden, which increases mental workload.	Incidents and malfunction of objects are unforeseen issues, which suddenly require attention and in time decision making and action. Being unprepared, this increases the experienced mental workload.	T1(1), K1(1), T2(1), S2(1)
	Blijf je even hangen.	Cognitive lock-up	Cognitive lock-up if suddenly an incident comes up. Shifts can be rather dull, when suddenly operators need to respond quickly to an incident.	S2(1)
Operator receives no direct feedback on own actions	Afwachting van gaat het goed. Goed bezig? Vergeet je niet?	No direct feedback whether operator made the right choice.	Operator decisions and actions do often not instantly change the situation. It takes time before the operator knows whether he made the right choices. Sometimes there is no feedback.	T1(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
Difficulty to access relevant information (Continues on next page)	Hoeveel programma's nodig om bij informatie te komen?	Multiple systems required to obtain information	Different systems contain information about the same element, for instance about a ship. Operators need multiple systems to access all relevant information.	I1(1)
	99 opties in elk systeem	Multiple ways to reach information	The same information can be accessed at different locations in the system and this can differ per location or user. It for instance differs which information is visible in a tooltip label.	I1(1)
	Prioriteit. Belangrijk. Door elkaar heen.	Priority of information is not visible	Importance of information is not visualized. A journal item of a malfunction of a sluice for instance is visualized the same as the weekly visit of the window cleaner. A collision is more important than how many free bollards there are.	K1(1)
	Hele lijsten scrollen. Heel Nederland in IVS voorzetten. Schepenlijsten zo lang zijn. Past maar zo'n blokje.	Long lists	System contains long lists of information, which require scrolling. This makes it time consuming to access information and difficult to obtain overview.	K1(1), OQ5(1)
	Per kwadrant maar aantal blokken. Hoeveel blokken. Klik, klik, klik.	Switch between information sources	The system can only show information of 4 regions at the same time. The larger the regions, the longer the lists in which operators have to search for information. They need to switch between regions. Not all information is directly available.	K1(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
Difficulty to access relevant information (Continuation of previous page)	Eerst moeten schakelen. Tussen 48 en 32. In loggen bij een andere regio. Vanuit het rijtje keizen. Welk gebied je wilt hebben.	Redo log in to access other information	The operators need to log in per region. The area of control has more regions. To access information of another region, they need to log in again and select this other region in the list of available regions.	K1(1)
	Ondoenlijk om bij te houden	Too much information	All unfiltered information of the entire region is now available. This is too much information to monitor.	K1(1)
	Muisklikken . (In journaal kijken) duurt erg lang. Door elkaar heen. Punten uit halen. Snel kunnen hebben. IVS trage factor.	Time consuming to find relevant information.	It sometimes takes time to find the required information. In journals, relevant information is mixed with irrelevant information.	I1(3), K1, OQ1(1), OQ2(1,5), OQ3(1), OQ5(0,5), OQ6(0,5)
	Kunnen vinden. Verstopt zit.	Hidden information	Some information is not directly visible. Mouse clicks and / or scrolling are required to access the information. The location where to find the information is not known.	I1(1), OQ1(0,5), OQ2(0,5), OQ3(0,5)
	Slecht leesbaar	Difficult to read	Information is difficult to read	OQ1(0,5)
	Punten uit halen. Dat skip je dan. Irrelevante informatie.	Irrelevant information	The systems contain irrelevant information. Journals for instance include a log of the weekly visit of the window cleaner.	K1(2), OQ1(0,5), OQ2(1), OQ3(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
ONM operators require the ability to improvise	Improvisatie-vermogen	Human ability to improvise is required	If information is not complete or correct, for instance when information changed, the operator needs the ability to improvise to deal with the situation.	I1(1)
Operators require large amount of information.	Kleiner gebied. In dit stuk. Landelijk gebied. Van oost tot west. Tot aan Schoonhoven. Zijn er nogal wat. Areaal groter. Corridor veel groter. Gebied groter.	Large area of control requires large amount of information	A large area of control requires a large amount of information, such as the names of a large amount of companies or roads located at the waterside.	I1(2), S1(1), T2(1)
	Kennis. Gewoon weten, Niveau hebben. Ballast. Rugzak. Handicap. NIet goed op situatie inspelen. Ervaring. Niveau.Onbekend. Niet zo bekend. Fouten mee gemaakt. Kennis van stoffen.	ONM RSA includes a lot of information, which is difficult to obtain and maintain without sufficient experience	In order to respond in a timely matter, a big amount of information is part of an operator's required situation awareness. Especially location specific traffic management information, like which limitations are there for specific routes, cargo types, or objects in the waterway. Operators believe this is only possible with enough experience in this specific area.	I1 (2), K1(1), S1(4), T2(2), S2(1)
Some information is required sporadic.	Nooit iets gebeurt. Klein bedrijfje. Niet zo vaak tegen.	Some information is required sporadic	Locations which seldom require attention are less known by the operator. Information about these locations is required sporadic. But in case of for instance an incident, this information is required.	I1(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
Some information is only available in operator's mind.	Niet direct zichtbaar. Tussen de oren. Weten. Ploeg wisselen. Nieuwe ploeg. Op MMI zien. In Digitaal Journaal heel kort en bondig, terwijl meer achtergrond informatie hebben.	Transfer problems for information only available in operator's mind.	Some information is only available in operator's mind, like the current status of an incident. When shifts change, operators need to transfer this knowledge to a colleague. This is true for both ONM operators and others who provide information.	K1(1), T2(1), K2(1), S2(1)
Current system automation does not support operator.	Alarmerings-systeem. Allemaal uitgeschakeld. Wordt er gek van. Omdat het teveel is. Helemaal bij vol.	Too many alarms generated by system.	Systems with alarms such as moving ships in areas outside the waterway and still ships in the waterways provide to many alarms. Too many alarms drives people crazy.	K1(1), I2(1)
	Alarm. Niet goed ingesteld. Er uit halen.	Irrelevant alarms generated by system.	Systems with irrelevant alarms, such as "ship on shore" alarms in inland waterways instead of sea, generate unnecessary mental workload.	K1(1)
	Als je hiervandaan 112 belt ga je nat. Verkeerde meldkamer.	Call automatically forwarded to wrong emergency room	112 phone calls are automatically forwarded to the emergency room based on the location of the caller. An ONM operator might call about a different location, and in this case is forwarded to the wrong emergency room.	S1(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
ONM operators miss, forget or skip relevant actions. (Continues on next page)	Automatisme. Bepaalde stappen. Vergeten. Lang mee draait. Uit het hoofd. Overslaan. Al jaren rondfietst.Overschatten. Onderschatten. Checklist. Automatische piloot. Spiekbriefje. Concentratie-problemen lage werkdruk	Miss / forget standard steps due to automatism when experienced.	Experienced operators do not strictly follow procedures. They think they know what needs to be done. Cause of this, they sometimes forget certain steps. They do not use the checklists.	K1(1), S1(3), S2(7), OC3(1), OC5(1)
	Procedures. Echt nodig. Dachten wij. Logica. Omdat je dat niet weet. Vind niet noodzakelijk.	Skip standard steps in procedures if relevance is unclear.	Operators sometimes consciously skip standard steps in procedures if the relevance of this step is unclear. They for instance do not inform a stakeholder if they do not understand why this stakeholder needs this information.	K1(2)
	Overschatten. Onderschatten. Foutieve aannames. Ervaring als informatiebron.	Over-generalize based on experience	Experienced operators think they know it all or know it better. They do not strictly follow procedures, over-generalize or over-simplify.	S1(2), S2(1)
	Toch wel weet. Goed doorvragen. Beperkte informatie. Verkeerde beslissingen.	Information not asked for	Not asking all relevant questions, due to experience draw premature conclusions. Therefore lacking information to take correct decisions.	S2(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
ONM operators miss, forget or skip relevant actions. (Continuation of previous page)	Niet ervaren. Niet inlichten bepaalde personen. Niet overal aan denkt.	Not informing due to inexperience	Not informing all relevant people due to inexperience.	S2(1)
	Met iets anders bezig. Lage werkdruk. Concentratie problemen.	Alertness and vigilance problems	Missing relevant information due to low workload and vigilance problems	OC1(1), OC3(1)
Insufficient cooperation with colleagues	Te laat opschalen. Zelf willen doen. Zelf willen oplossen.	High threshold to give responsibility to superior	Operators tend to solve problems themselves. There is a high threshold to give responsibility to a superior.	K1(1)
	Oud zeer. Heilige huisjes. Verwijten. Vroeger. Verleden. Ander eigenlijk hoorde te doen.	Reluctance of others to cooperate with ONM due to history.	In the past, different roles and regions worked more independently. Other roles were responsible for tasks which are now part of the ONM tasks. Resistance to change and / or not willing to let go own responsibility can result in reluctance of others to cooperate	K1(1)
	Onafhankelijk van elkaar werken. Zegt assistentie ONM'er, maar dat doet bijna niemand.Geen antwoord krijgen. Geen medewerking.	No collaboration with other roles	ONM operator requires information from others. Other roles should proactively inform ONM operators, but do not always do so.	T1(1), K1(1), S1(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
Communica-tion errors and ineffective-ness. (Continues on next page)	Komt over alsof. Terwijl wij zoiets hadden van. Eigenlijk overbodig. Op de juiste manier overgebracht. Communiceren apart verhaal.	ONM operator does not communi-cate effective.	Effective communication with others sometimes is difficult. Operators for instance judge a situation as not urgent, but do not communicate this judgement. Others, depending on their information, therefore can misinterpret the situation, resulting in wrong decisions and actions.	K1(1)
	Net wat meegemaakt. In paniek. Tekeer gaat. Boze meneer. Uit zijn plaat gaat.	Emotional or stressed informants difficult to understand.	Informants sometimes have difficulty to communicate effectively due to emotions or stress. For instance when they are in an incident, angry about a situation or touched by what they saw.	K1(2), S2(1)
	Het enigste wat hij zei. Zo’n kleine melding. Waar het over ging.	Informant does not communi-cate severity of incident.	Informants sometimes provide a minimum of information, which is difficult to interpret. A skipper for instance only mentioned he "sailed against a ferry", while this was a sever collision and people needed help as soon as possible.	K1(1)
	Over drie of vier schijven heen. Belt met. Fout gaan onderweg. Wist nergens van. Communicatie is altijd het grote issue.	Communi-cation errors between different involved parties	Different parties are involved in actions. Evaluations show communication errors is common issues. Communication errors between different parties result in failure to perform action. The ONM calls the control room, who calls the maintenance organization, who calls the planning office who calls the mechanic.	S1(1), K2(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
Communica-tion errors and ineffective-ness. (Continuation of previous page)	Niet duidelijk is. Anders binnen komt.	Information of informant unclear	Information of informant is not clear. Information difficulties.	S2(2), OC1(1), OC4(1)
ONM operator takes wrong or no timely action	Tijdsdruk. Te weinig tijd. A la minute. Elke seconde telt. Geen tijd.	Time pressure	Multiple tasks requiring time-constrained decisions and actions for a large area of control in unpredictable conditions sometimes results in time pressure.	K1(1), T2(1), S2(1)
	Ervaren iemand vlotter dan iemand niet ervaren.	Slower due to inexperience	Slower actions due to inexperience.	S2(1)
	Verkeerde instanties inlichten. Onervarenheid	Inform wrong authorities	Inform wrong authorities due to inexperience	S2(1)
	Foute volgorde van afhandeling. Onervarenheid	Wrong order of actions	Wrong order of actions due to inexperience	S2(1)
Required information of others unreliable (Continues on next page)	Afhankelijk van info van derden, van buiten af. Een schipper meld. Degene die doorgeeft. Doorvragen. Informatie niet direct. Ze niet bellen.	Depend on information of others	Operators depend on information provided by others, such as skippers, to obtain situation awareness. This can go wrong.	T1(2), I1(1), K1(1), T2(1), K2(1), S2(1), OC1(1)
	Niet gebeld. Niet gemeld. Niet aangemeld schip. Vergeten door te geven.	Missing relevant information from others.	If informant operator or eyewitnesses do not contact operator, there is no information	K1(2), ON(1), OQ1(1), S2(1)

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Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
Required information of others unreliable. (Continuation from previous page)	Diegene heeft hele plaatje niet. Staat daar alleen.	Informants have difficulty to inform, since they only have fragmented information, no overview	The ONM operator is interested in the effect of issues on the entire area of control. Informants are usually more locally oriented. They do not have the insight or information to understand the bigger picture. Informants therefore have difficulty to directly provide the required information. ONM operators need to ask the right questions.	K1(1), K2(1)
	Blijkt later dan. Is dat wel zo. Interpreteren. Blijkt het een hondje te zijn.	Informants misinterpret situation, provide wrong information	Informants sometimes misinterpret the situation and thus provide wrong information. This is difficult to judge. For instance a skipper can be convinced someone attacks a girl on a bike. While actually the girl fell and a guy tried to catch her.	K1(1), S2(2)
	Veel te laat. Tijdig geïnformeerd	No timely information from others.	Informants sometimes informs late.	K1(1), T2(1)
Operator's perception of RSA larger than actual RSA	Te veel wilt monitoren. Kunst van het weglaten. Allemaal. Breedvoerig.	Perception of RSA larger than actual RSA	Operators tend to consider a lot of information as highly important, they want to know everything. Also information which is not part of the required situation awareness.	K1(2)
Insufficient quality of information in systems (Continues on next page)	Door MIB (Duitse IVS) angeleverde gegevens kloppen regelmatig niet. Niet correct.	Wrong information Germany.	Information provided by the German IVS system (destination, amount of people on board) is often incorrect.	OQ1(2,5), OQ2(1), OQ3(0,5), OQ6(0,5)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
Insufficient quality of information in systems (Continuation from previous page) (Continues on next page)	Een schip op AIS al ziet bij Breukelen, jij hebt hem hier voor de sluis. Overhalen. Doorgelopen. Voorloopt. Overeen komen met werkeljkheid. Niet synchroon. Past information in IVS90 aan.	Dynamic information results in wrong information in system	System displays ships in wrong location of the waterways. The system processes information about ships to provide insight in their location. This sometimes goes wrong. This is a common error if ships take a rest, and the system thinks the ship continued its journey. Information about ships (destination, cargo, ...) changes, but this is not always correctly changed in the system. In that case, the ONM changes this information in IVS90.	K1(1), ON(2), OC2(1)
	Wel goed staan. In FIS staan ze niet goed.	Wrong information FIS	Information, such as the headroom of bridges, is not always displayed correctly in FIS.	I2(1)
	Niet iedereen AIS heeft. Drukker dan op AIS beeld. Niet sluitend kan zijn. Fouten maken. Missende gegevens. Voegt schip toe in IVS. Telefoonnummers objecten / schepen.	Missing information	Not all ships, especially recreational boats, have an AIS transponder. The AIS system therefore does not visualize all ships. Not all relevant information about ships is available in the system. ONM operators contact skippers to add the missing information. Missing phone numbers of objects and ships. Only metrological information about certain points on the corridor.	S1(1), ON(4), OQ1(2,5), OQ2(1), OQ3(1), OQ4(1), S2(1), OC1(1), OC2(1), OC4(1)
	Documenteren. Even invullen.	Information not logged	Incidents not logged sufficiently by colleague operators. Therefore missing information after shift change.	S2(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
Insufficient quality of information in systems (Continuation from previous page)	Tegenstrijdige informatie	Contra-dictory informa-tion	Systems show contradictory information	OQ1(0,5), OQ2(0,5), OQ3(0,5), I2(1)
	Niet betrouwbaar	Informa-tion not reliable	Information is not reliable.	OQ1(0,5), OQ2(1), OQ3(0,5), OQ5(0,5), OQ6(0,5)
	Achterlopen.	System lags behind	System lags behind reality.	OQ1(0,5), OQ3(1), OQ5(0,5)
	Actuele informatie. Gaat uren overheen. Blijven hangen. Niet afgemeld. Niet doorgeven. Afmelden.	Informa-tion not up to date	It sometimes takes long before others inform the ONM operator about a change, for instance when a obstruction is dissolved, this is not always mentioned straight away. It can take hours. No status update	T2(3)
	Dubbele meldingen. Zelfde reis. Zelfde schip. Verschillende reizen.	Redun-dant informa-tion	IVS90 often contains multiple reports of one ship, like multiple journeys of one ship, or multiple reports of one journey.	OQ1(1)
ONM goals do not all receive the required amount of operator's attention.	Handelen uit achtergrond, rol Scheepvaart. Verkeersleiders. Sluismeesters.	Focus of atten-tion influen-ced by back-ground	ONM role is combined with VTS role. ONM therefore thinks from a VTS point of view and can forget other relevant viewpoints, like water management viewpoint.	S1(3), S2(1)
	Verder ziet. Focust op incident. Verder op het netwerk. Effectgebied. Meer overall kijken. Geheel overziet.	Local focus, no network over-view	Focus too much on incident area, instead of on the area influenced by the incident.	S2(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
Mental workload exceeds operator's mental capacity.	Meer dan je lief is. Meer werk. Minder doen omdat het teveel is. Blijven dingen liggen. Door drukte.	Workload exceeds capacity	Sometimes the workload can be too high. Operators cannot carry out all tasks, such as logging, during incidents.	S1(1), OQ1(1), OQ2(1), I2(1)
	Gilldend gelk. Alle vragen. Niks weten.	Many questions to answer during sever incident	During sever incidents, the operators need to inform higher officers, who are less familiar with many (local) details. They therefore need to answer a large amount of questions, resulting in a high workload.	I2(1)
	Door drukte, telefoons. Dingen gaan vergeten.	Distraction by phone calls	In busy situations, with many phone calls, operators forget certain actions	I2(1)
Criticism about work of civil servants limits freedom of actions.	Als ambtenaar. Je mag niet. Wordt die boos. Doen we niet. Heb je die weer. Paar tikken om de oren. Jou naam hangt. Frank waarom?	Criticism about work of civil servant limits freedom of actions	As a civil servant, their work is often in the spotlight and criticised. This limits their freedom of actions, feel like they cannot do something extra or improvise.	S1(1), T2(1)
System does not support efficient insertion of information	Onnodige / overbodige vragen invullen in Infraweb	Irrelevant actions in system	Infraweb forms require operator to answer irrelevant questions.	OQ2(1)
	Invoeren informatie kost veel tijd.	Time consuming to insert information	Time consuming to insert information in systems	OQ1(0,5), OQ2(0,5), OQ3(1), OQ5(0,5)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
Required system not fully functional or available	Minuten zoeken. Vlot. Rijkswaterstaat systemen. Traagheid. Wachten. Rijk en ICS niet geslaagd huwelijk. Bakje koffie doen. Internetsnelheden. Afhankelijk van netwerk. Zeer trage PC. Verbindings-problemen. Downstream. Drama.	Slow system	Many systems used by the operators are very slow. It takes minutes to load a new page or respond to a command. Especially systems which require Internet are slow.	I1(1), K1(1), ON(1), OQ1(1), OQ2(2), OQ3(1), OQ5(1), OQ6(1), I2(1)
	Bang voor systemen. Ramp.	System deficiencies	Required systems do not function well enough.	K2(1)
	Klikt ergens op, werkt niet. Zit je vast. Vast loopt. Alles kwijt. Uitval van systemen. Ligt er uit.	System crash	Systems used by the operator sometimes crash, nothing works and the lose information.	K1(2), OQ1(1), OQ2(1), OQ3(0,5), OQ5(1), OQ6(1), K2(1)
	24/7 ondersteuning. Helpdeks. Staat niet in contract.	Inefficient system support	Due to outsourcing of system support, some problems are not solved, since they are not mentioned in the contract. There is often no 24/7 support, while the operators work 24/7.	K2(1)
	Token verlopen.	Back-up laptop not available	Back-up laptop not available since token is cancelled. Back-up laptop needs to be logged on once every 3 months, or token is cancelled.	K2(1)

Continuation from previous page

Description	Raw data indicators	Textual descriptor	Explanation	Source (Freq.)
Operator experiences physical complaints	Hoofdpijn	Headache	Operator experiences severe headaches during work	OQ1(1)
	Vermoeidheid	Fatigue	Operator experiences sever fatigue during work	OQ1(1)
	Pijn in handen, polsen, armen	RSI	Operator experiences mild RSI symptoms	OQ2(1)
	Snel eten, ongekauwd.	Eating difficulties	Due to communication with skippers, operator has difficulty to eat. Operator wants to quickly respond, which is difficult with a mouth full of food.	OQ2(1)
	Pijn in schouders, rug, nek	Back pain	Operator experiences mild pain in shoulders, back and neck.	OQ6(1)
Time component of information not supported by systems.	Tijdsbalk. Volgende week. Verschijnt. Outlook agenda. Aflosser. Handmatig up to date houden.	Time component of information not supported by systems.	Some received information is not relevant at the moment, but in future. Or only relevant for a certain time span. There is no support to store this type of information for future use, while hiding it as long as this information is not relevant.	T2(1)

APPENDIX V

OVERVIEW OF SYNTACTIC-SEMANTIC PROCESSING STEP 5 - 8

This appendix shows an overview of all the identified deficiencies. Table over multiple pages.

Description at meaningful abstraction level	**Influential factor**	**SA aspect**	**Category**
Insufficient quality of information in systems.	System factors	SA knowledge	Informing
Current information presentation puts high demands on operator's ability to keep overview of a large area of control.	System factors Human factors	SA assessment	Informing
Difficulty to access relevant information.	Information needs	SA assessment	Informing
Required information of others unreliable.	Information needs	SA knowledge	Circumstances Cooperation
Required system not fully functional or available	System factors	SA assessment	Circumstances
ONM operators miss, forget or skip relevant actions.	Human factors	-	Workflow
Operators require large amount of information.	Information needs	Required SA	Informing
Communication errors and ineffectiveness.	Human factors	SA knowledge	Cooperation
ONM requires to pursue multiple tasks simultaneously.	Goals & Task Factors	Required SA	Circumstances
ONM operators do not follow a uniform working method.	Human factors	SA assessment	Workflow
ONM operators take wrong or no timely action	Human factors	-	Workflow
Insufficient cooperation with colleagues	Human factors	SA assessment	Cooperation Workflow

Continuation from previous page

Description at meaningful abstraction level	Influential factor	SA aspect	Category
Mental workload exceeds operator's mental capacity.	Human factors	SA assessment	Ability
ONM by essence deals with unforeseen and unplanned issues	Goals & Task Factors	-	Circumstances
Collaborating stakeholders do not follow a uniform working method.	Human factors	SA assessment	Circumstances Cooperation
Some information is subject to change.	Information needs	Required SA	Circumstances Informing
ONM operators are exposed to stressful situations	Human factors	SA assessment	Circumstances
Some information is only available in operator's mind.	Information needs Human factors	SA knowledge	Informing
Current system automation does not support operator.	System factors	SA assessment	Informing
ONM goals do not all receive the required amount of operator's attention.	Human factors	Required SA	Workflow
ONM actions have far-reaching consequences.	Goals & Task Factors	-	Circumstances
Operator experiences physical complaints	Human factors	-	Circumstances
Criticism about work of civil servants limits freedom of actions.	Goals & Task Factors	-	Circumstances
System does not support efficient insertion of information	System factors	SA assessment	Workflow
External processes influencing ONM tasks take long.	Goals & Task Factors	-	Circumstances
Operator receives no direct feedback on own actions.	System factors	SA assessment	Informing
ONM operators require the ability to improvise.	Human factors	SA assessment	Ability
Some information is required sporadic.	Information needs	SA assessment	Circumstances Informing
Operator's perception of RSA larger than actual RSA	Human factors	Required SA	Workflow
Time component of information not supported by systems.	System factors	-	Informing

APPENDIX VI

USE CASES OF DETAILED DESIGN 1

This appendix shows the use cases developed to discuss detailed design 1. These use cases were implemented in an interactive prototype.

Use case A: Malfunction of lock

Situation: It is summer. Near the Oranjesluis, a lock with four chambers, shipping consists of professional shipping and a lot of recreational vessels. In normal circumstances, one lock chamber is reserved for recreational vessels. In normal circumstances, the waiting times for this lock are about 20 minutes on both sides. Due to a sudden failure, the chamber for recreational vessels cannot be used for one week, seven days. The skippers are not yet informed. To solve the problem, the following traffic measures need to be set:

- Two chambers remain fully available for professional shipping and empty spots care filled with recreational vessels
- One chamber is used for small professional and recreational vessels with the principle ‘who comes first, goes first’.

Step	Description
A.1	Operator notes that lock Oranjesluis is not functional due to a failure; one of the four chambers is not available for an indefinite period of time.
A.2	Operator determines scope and nature of the restriction
A.3	Operator determines impact of restrictions on volume of traffic
A.4	Operator forecasts (expected) traffic image in the planning area (crowdedness, use, ports and terminals)
A.5	Operator forecasts (expected) use of locks
A.6	Operator determines traffic measures on basis of the catalogue of measures
A.7	Operator adapts the lock control regime: Two chambers remain fully available for professional shipping and empty spots care filled with recreational vessels. One chamber is used for small professional and recreational vessels with the principle ‘who comes first, goes first’.
A.8	Operator assesses the need for additional traffic measures
A.9	Operator internally informs VTS- and lock operators about adjustment of control regime
A.10	Operator announces the adjustment of control regime through VHF
A.11	Operator announces the adjustment of control regime as ‘notice to skippers’ text message
A.12	Operator classifies restriction (malfunction / damage)
A.13	Operator contacts contractor to solve the malfunction / damage

Use case B: Planned restrictions

Situation: At a rather narrow part of the Rhine (where large vessels normally can pass each other) work should be carried out. The job to be done is replacing a barrel. The total time required for this job is two hours, during which one-way traffic needs to be in place for vessels larger than 130 meter, and for Vessels carrying one or multiple blue cones due to dangerous cargo. There still is a need to grant a permit for the work. Besides, the work must be announced. And a VTS operator needs to manage traffic.

Step	Description
B.1	Operator observes planning area
B.2	Operator determines scope and nature of the planned restrictions
B.3	Operator receives plan of action planned restriction
B.4	Operator reviews the traffic measures proposed in the plan of action
B.5	Operator contributes to plan of action
B.6	Operator determines impact restrictions on volume of traffic
B.7	Operator forecasts (expected) traffic image within the planning area (crowdedness, use, in time…)
B.8	Operator internally informs VTS- and lock operators about traffic measures
B.9	Operator sets temporary adjustment of traffic rules (one-way traffic for vessels larger than 13o meter and / or vessels carrying one or more blue cones)
B.10	Operator registers set traffic measures
B.11	Operator announces the restriction and traffic measures as ‘notice to skippers’ text message
B.12	Operator announces the restriction and traffic measures through VHF
B.13	Operator internally informs VTS- and lock operators about lifting temporary adjustment of traffic rules
B.14	Operator lifts temporary adjustment of traffic rules
B.15	Operator announces lifting up the temporary adjustment of traffic rules

APPENDIX VII

USE CASES OF DETAILED DESIGN 2

This appendix shows the use cases developed to discuss detailed design 2 with the expert team and operator sounding board. These use cases were implemented in an interactive prototype. The color coding in the tables shows what type of steps are anticipated. The following color coding is used:

Type of step
Human
System
Human – System Interaction

Use case C: Set traffic measures after colleague VTS operator reported an incident through his traffic management system

Step	Description
C.0	The system generates a notification at the N-ONM user interface
C.1	The operator double clicks the notification bar to take on the notification
C.2	The system displays the notification overview window and notification detail window of the clicked notification
C.3	The operator sees that the system proposes to execute certain actions
C.4	The operator decides that these are the correct actions to take
C.5	The operator clicks at ‘display area of focus incident’ in the list of proposed actions
C.6	The system displays a selection window to allow the operator to determine where to display the area of focus
C.7	The operator indicates where in the user interface to display the area of focus
C.8	The system displays the area of focus at the chosen location in the user interface
C.9	The operator clicks at ‘alarm emergency services’ in the list of proposed actions
C.10	The system connects with the emergency services by phone
C.11	The operator communicates with the emergency services by phone
C.12	The system in the notification detail window adapts the status of action ‘alarm emergency services’ to ‘Done’
Use case continues on next page	

Step	Description
Continuation from previous page	
C.13	The operator clicks at ‘send notice to skippers’ in the list of proposed actions
C.14	The system displays the notices to skippers overview and detail window. The notices to skippers detail window already contains details about the message to be published.
C.15	The operator completes the notice to skippers and adds to which areas this message applies
C.16	The operator clicks ‘Execute’
C.17	The operator clicks at ‘virtual buoyage’ in the list of proposed actions
C.18	The system displays the measurements overview and detail window. The measurements detail window already contains details about the virtual buoyage to be placed.
C.19	The operator completes the data required to place virtual buoyage
C.20	The operator clicks ‘Execute’
C.21	The system adds the measurement to the measurement overview window
C.22	The operator clicks at ‘contact patrol vessel’ in the list of proposed actions
C.23	The system contacts the patrol vessel which is closest to the incident location by phone
C.24	The operator communicates with the patrol vessel by phone
C.25	The operator decides to place a text at a dynamic shipping panel (DSP), an information panel located near the incident
C.26	The operator clicks the tab ‘DPS’ at the top of his information overview window
C.27	The system displays the DPS information overview and detail window
C.28	The operator selects the relevant DSP in the list of DSPs displayed in the information overview window
C.29	The system displays the detail window of the selected DSP
C.30	The operator types the text that he wants to display at the DSP in the detail window of the DSP
C.31	The operator clicks ‘Save’
C.29	The operator clicks the button ‘Back to notification’
C.30	The operator adds a comment in the notification detail window about placing a text at the DSP near the incident
C.31	The operator clicks the ‘Close’ button in the notification detail window
C.32	The system closes the notification
C.33	The operator contacts the VTS operator that reported the incident through phone

Use case D: Set traffic measures to handle planned restriction

Step	Description
D.0	The system generates a notification at the N-ONM user interface
D.1	De ONM right clicks the notification icon in area of focus window 1 (AoF1) and selects 'Focus in AoF2'.
D2	The system displays area of focus window 2 (AoF2), in which a map displays the area to which the notification is linked.
D.3	The operator double clicks the notification in the notification bar
D.4	The system displays the notification overview window and notification detail window of the clicked notification
D.5	The operator clicks at 'review plan of action' in the list of proposed actions
D.6	The system displays the restrictions overview and detail window. The detail window displays the plan of actions of the selected notification.
D.7	The operator review the information displayed in the plan of actions
D.8	The operator decides that these are the correct actions to take
D.9	The operator clicks the button 'Confirm'
D.10	The system closes the restrictions overview and detail window
D.11	The operator double clicks the notification in the notification bar
D.12	The system switches back to the notification overview and detail window
D.13	The operator clicks the button 'Close
D.14	The system closes the notification
D.15	The system displays a notification in the notification bar
D.16	The operator double clicks the notification in the notification bar
D.17	The system displays the notification overview window and notification detail window of the clicked notification
D.18	The operator clicks at 'Set one-way traffic' in the list of proposed actions
D.19	The system displays the measurements overview and detail window. The measurements detail window already contains details about the one-way traffic to be set.
D.20	The operator clicks 'Execute'
D.21	The operator double clicks the notification in the notification bar
D.22	The system displays the notification overview window and notification detail window of the clicked notification
D.23	The operator clicks the button 'Close
D.24	The system closes the notification

Use case E: Set traffic measures to handle unplanned restriction

Step	Description
E.0	The system generates a notification icon in the area of control and area of focus maps and notification bar
E.1	The operator moves the mouse cursor over the icon in the area of focus map
E.2	The system shows a tooltip near the icon which indicates malfunctioning of lock Zuidersluis
E.3	The operator double clicks the icon
E.4	The system displays the notification overview window and notification detail window of the clicked notification
E.5	The operator review the proposed actions displayed in the detail window
E.6	The operator decides that these are the correct actions to take
E.7	The operator views the area of focus map to verify that there are no long waiting times at the involved locks
E.8	The operator verbally informs the lock operators and head operator, who are located in the same room
E.9	The operator clicks at 'temporally adapt control regime' in the list of proposed actions
E.10	The system displays the measurements overview and detail window. The measurements detail window already contains details about the propsed changes to the lock control regime
E.51	The operator clicks 'Execute'
E.62	The system switches back to the handling of the notification
E.73	The operator determines whether the traffic measure has the desired effect
E.84	The operator decides that no further actions are required

Use case F: Adapt user interface to view incident

Step	Description
F.0	The operator decides to open an area of focus window to view the location of a vessel run aground
F.1	The operator clicks the tap 'Personal settings GUI' at the top of his information overview window
F.2	The system displays the personal settings overview and detail information window. The detail window displays a schematic picture of the GUI
F.3	The operator selects the area in the lower left of the screen
F.4	The operator selects 'GIS – AOF' in the listbox and then 'Location notification x'
Use case continues on next page	

Step	Description
Continuation from previous page	
F.5	The operator clicks 'Execute'
F.6	The system displays an area of focus window in the lower left of the screen. The map is zoomed in on the location of the notification
F.7	The operator clicks the button 'Back to notification'

Use case G: Set traffic measures to handle ascending waiting time

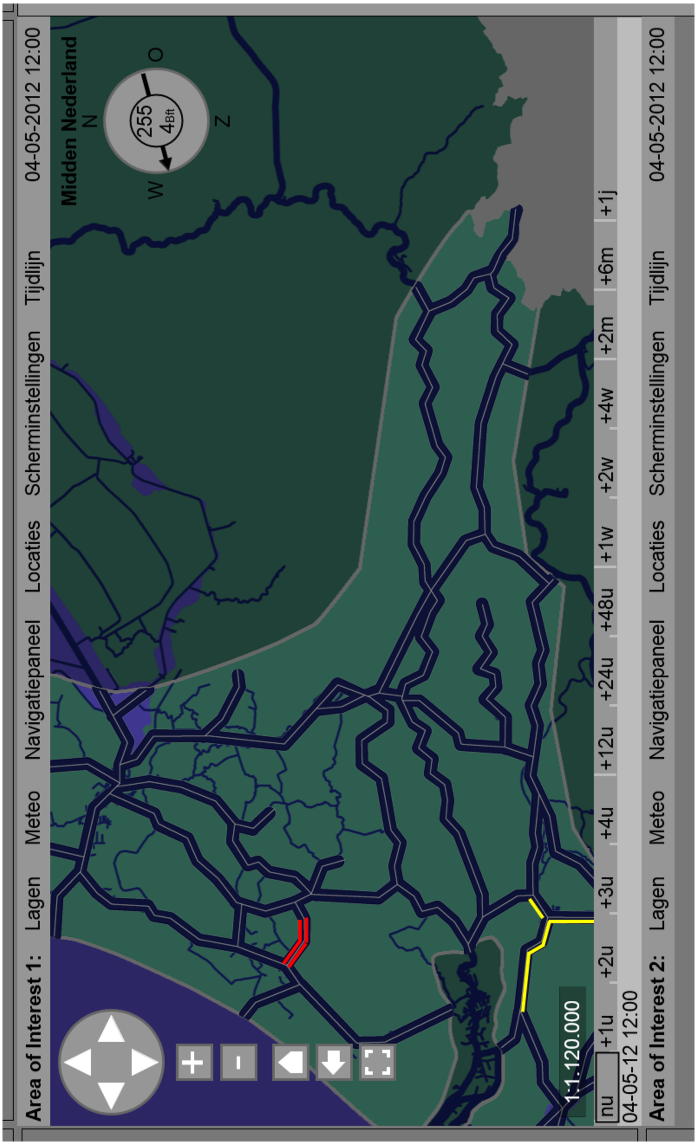
Step	Description
G.0	The operator decides to view the traffic volume prognosis of 4 hours in future
G.1	The operator shifts the time in the timeline to 4 hours in the future
G.2	The system shows a forcast of the future situation. The queues at lock Oranjesluizen increased.
G.3	The operator sees that the icon indicatest that the prognosed waiting times at lock Oranjesluizen are too high compared to what is considered acceptable
G.4	The operator moves the mouse cursor over the icon of the lock Oranjesluizen
G.5	The system, among other things, displays the increased waiting times
G.6	The operator decides to set a traffic measure to only turn the lock Oranjesluizen when completely filled
G.7	The operator clicks the tab 'Measurements' at the top of his overview window
G.8	The system displays the measurements overview window and measurements detail window
G.9	The operator clicks the button 'New measurement'
G.10	The operator selects the measurement 'Turn lock completely filled'
G.11	The operator selects the lock 'Oranjesluizen'.
G.12	The operator enters the start date and time
G.13	The operator enters the end date and time
G.14	The operator clicks 'Save'
G.15	The system adds the traffic measure to the measurements overview window

Appendix VIII

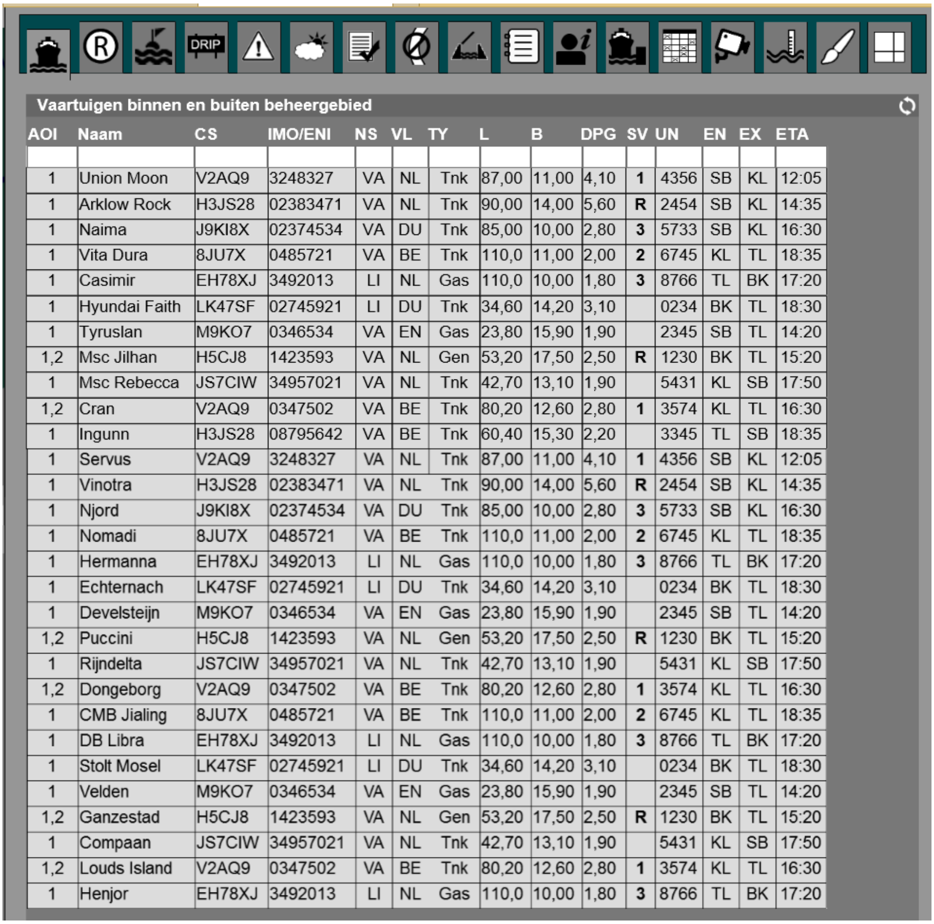
APPENDIX VIII

SCREENSHOTS OF USER INTERFACE CONCEPTS

Area of Focus window of detailed design 2



Information overview window of detailed design 2



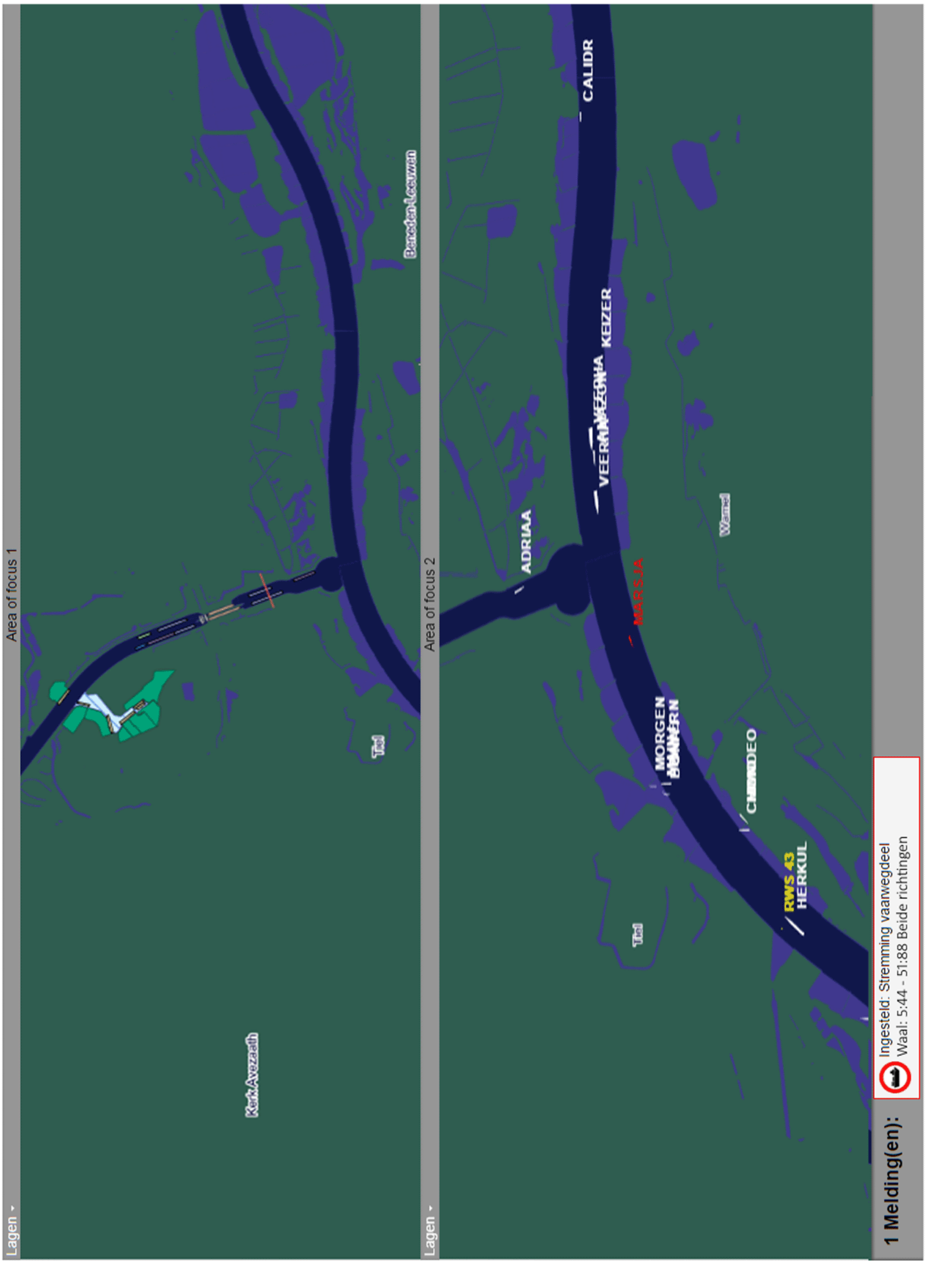
Vaartuigen binnen en buiten beheergebied

AOI	Naam	CS	IMO/ENI	NS	VL	TY	L	B	DPG	SV	UN	EN	EX	ETA
1	Union Moon	V2AQ9	3248327	VA	NL	Tnk	87,00	11,00	4,10	1	4356	SB	KL	12:05
1	Arklow Rock	H3JS28	02383471	VA	NL	Tnk	90,00	14,00	5,60	R	2454	SB	KL	14:35
1	Naima	J9KI8X	02374534	VA	DU	Tnk	85,00	10,00	2,80	3	5733	SB	KL	16:30
1	Vita Dura	8JU7X	0485721	VA	BE	Tnk	110,0	11,00	2,00	2	6745	KL	TL	18:35
1	Casimir	EH78XJ	3492013	LI	NL	Gas	110,0	10,00	1,80	3	8766	TL	BK	17:20
1	Hyundai Faith	LK47SF	02745921	LI	DU	Tnk	34,60	14,20	3,10		0234	BK	TL	18:30
1	Tyruslan	M9KO7	0346534	VA	EN	Gas	23,80	15,90	1,90		2345	SB	TL	14:20
1,2	Msc Jilhan	H5CJ8	1423593	VA	NL	Gen	53,20	17,50	2,50	R	1230	BK	TL	15:20
1	Msc Rebecca	JS7CIW	34957021	VA	NL	Tnk	42,70	13,10	1,90		5431	KL	SB	17:50
1,2	Cran	V2AQ9	0347502	VA	BE	Tnk	80,20	12,60	2,80	1	3574	KL	TL	16:30
1	Ingunn	H3JS28	08795642	VA	BE	Tnk	60,40	15,30	2,20		3345	TL	SB	18:35
1	Servus	V2AQ9	3248327	VA	NL	Tnk	87,00	11,00	4,10	1	4356	SB	KL	12:05
1	Vinotra	H3JS28	02383471	VA	NL	Tnk	90,00	14,00	5,60	R	2454	SB	KL	14:35
1	Njord	J9KI8X	02374534	VA	DU	Tnk	85,00	10,00	2,80	3	5733	SB	KL	16:30
1	Nomadi	8JU7X	0485721	VA	BE	Tnk	110,0	11,00	2,00	2	6745	KL	TL	18:35
1	Hermanna	EH78XJ	3492013	LI	NL	Gas	110,0	10,00	1,80	3	8766	TL	BK	17:20
1	Echternach	LK47SF	02745921	LI	DU	Tnk	34,60	14,20	3,10		0234	BK	TL	18:30
1	Develsteijn	M9KO7	0346534	VA	EN	Gas	23,80	15,90	1,90		2345	SB	TL	14:20
1,2	Puccini	H5CJ8	1423593	VA	NL	Gen	53,20	17,50	2,50	R	1230	BK	TL	15:20
1	Rijndelta	JS7CIW	34957021	VA	NL	Tnk	42,70	13,10	1,90		5431	KL	SB	17:50
1,2	Dongeborg	V2AQ9	0347502	VA	BE	Tnk	80,20	12,60	2,80	1	3574	KL	TL	16:30
1	CMB Jialing	8JU7X	0485721	VA	BE	Tnk	110,0	11,00	2,00	2	6745	KL	TL	18:35
1	DB Libra	EH78XJ	3492013	LI	NL	Gas	110,0	10,00	1,80	3	8766	TL	BK	17:20
1	Stolt Mosel	LK47SF	02745921	LI	DU	Tnk	34,60	14,20	3,10		0234	BK	TL	18:30
1	Velden	M9KO7	0346534	VA	EN	Gas	23,80	15,90	1,90		2345	SB	TL	14:20
1,2	Ganzestad	H5CJ8	1423593	VA	NL	Gen	53,20	17,50	2,50	R	1230	BK	TL	15:20
1	Compaan	JS7CIW	34957021	VA	NL	Tnk	42,70	13,10	1,90		5431	KL	SB	17:50
1,2	Louds Island	V2AQ9	0347502	VA	BE	Tnk	80,20	12,60	2,80	1	3574	KL	TL	16:30
1	Henjor	EH78XJ	3492013	LI	NL	Gas	110,0	10,00	1,80	3	8766	TL	BK	17:20

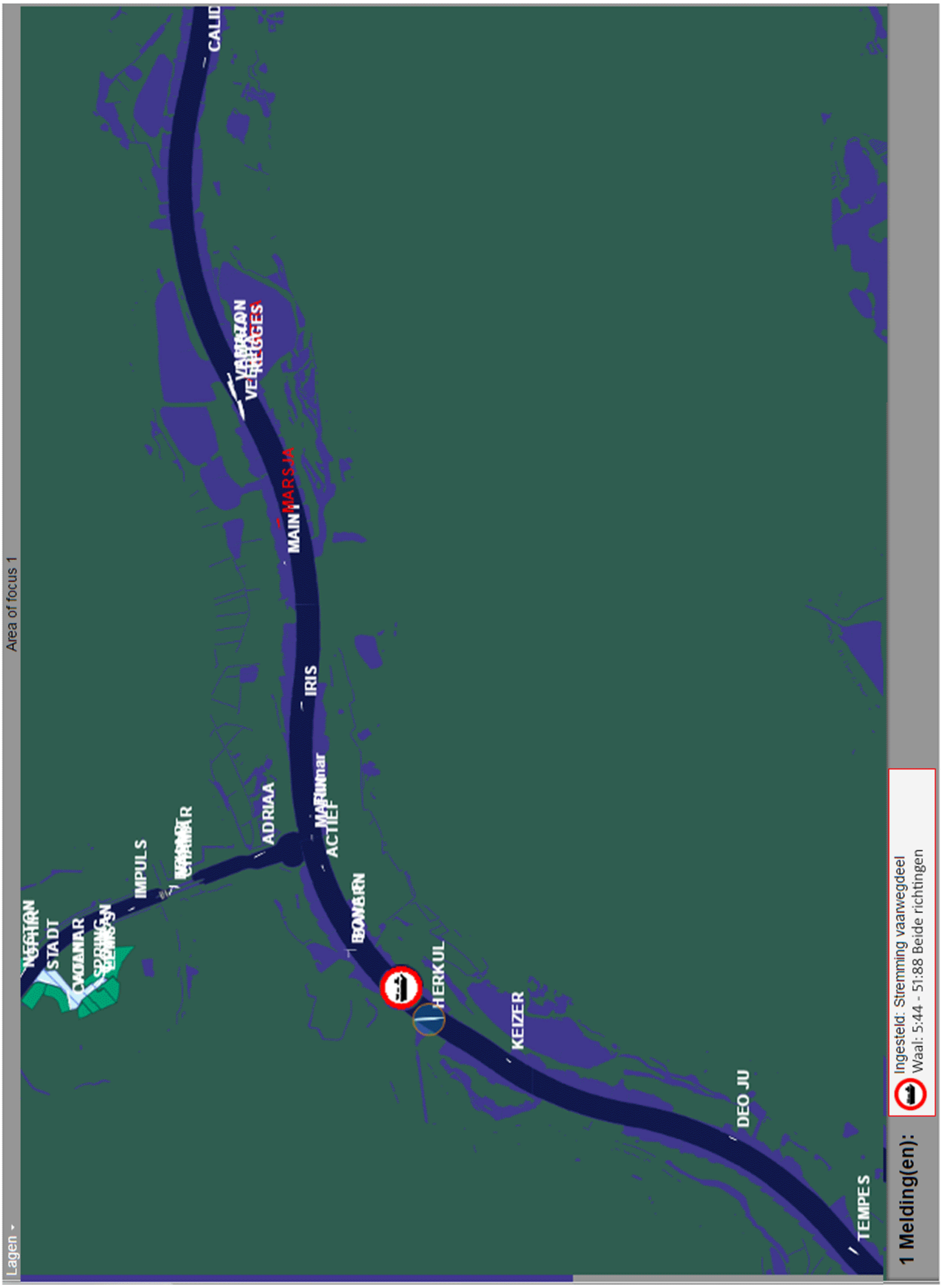
Information detail window of detailed design 2

Appendix IX

Area of Focus windows of coherent UI

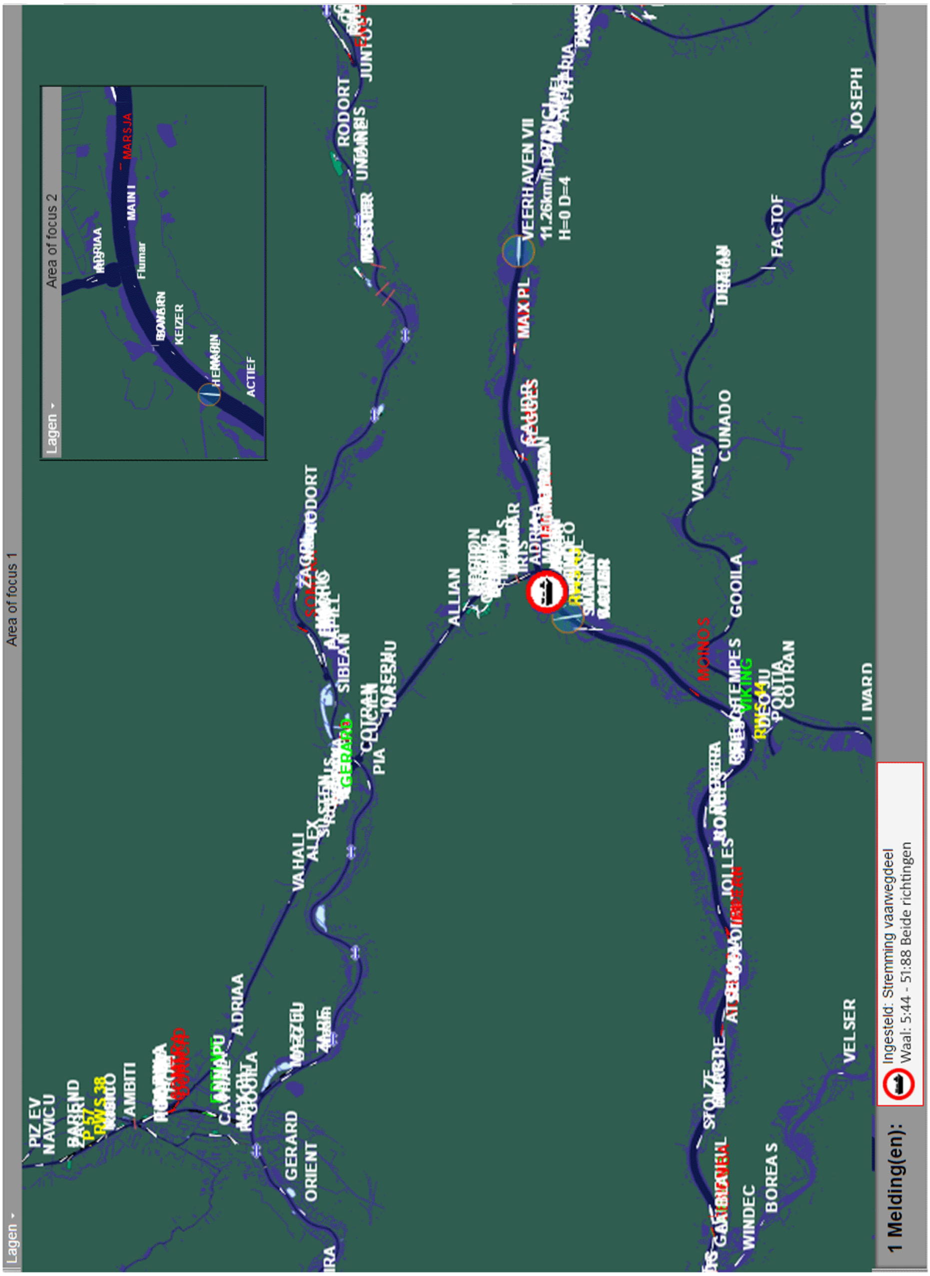


Area of Focus window of integrated UI

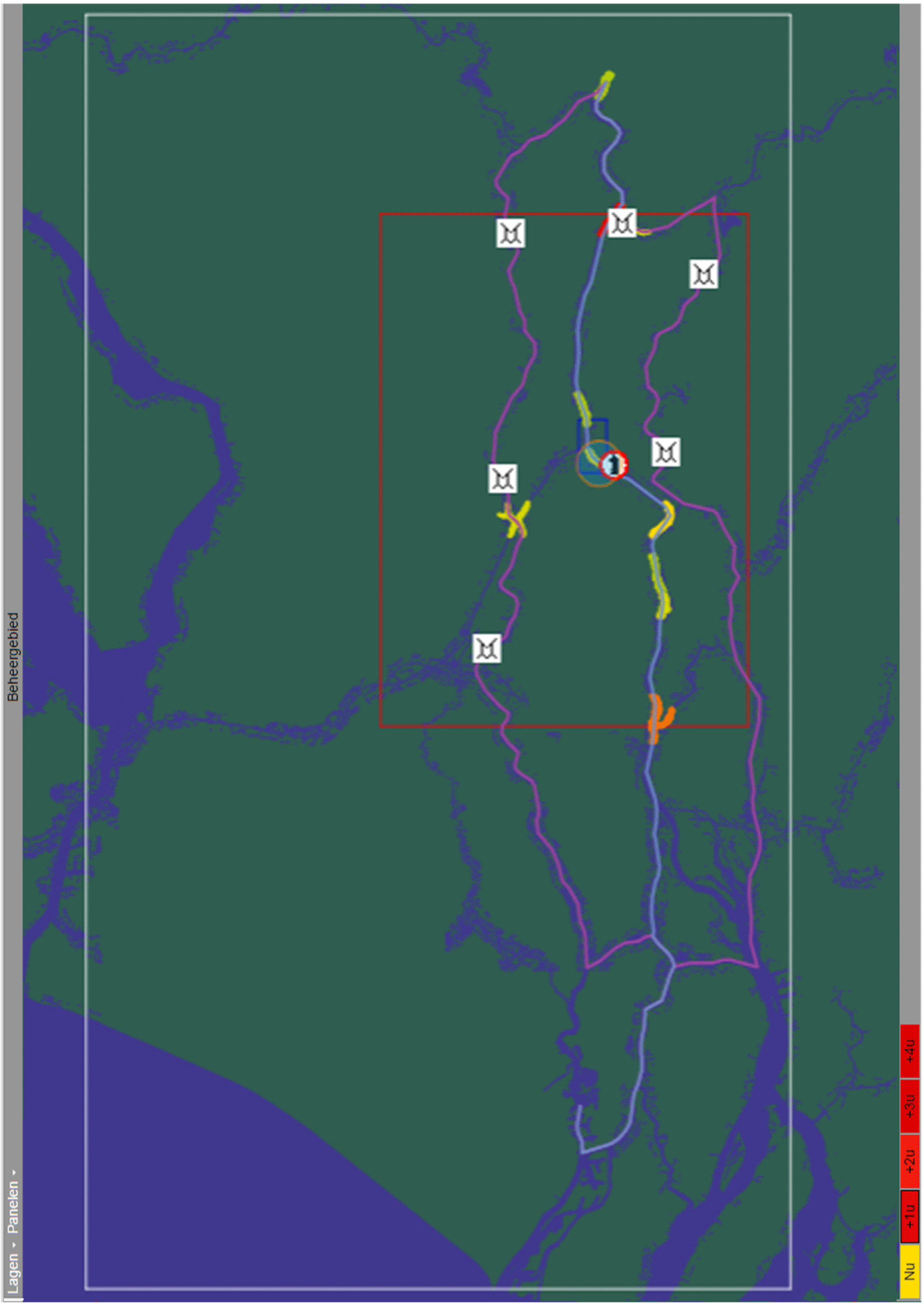


Appendix IX

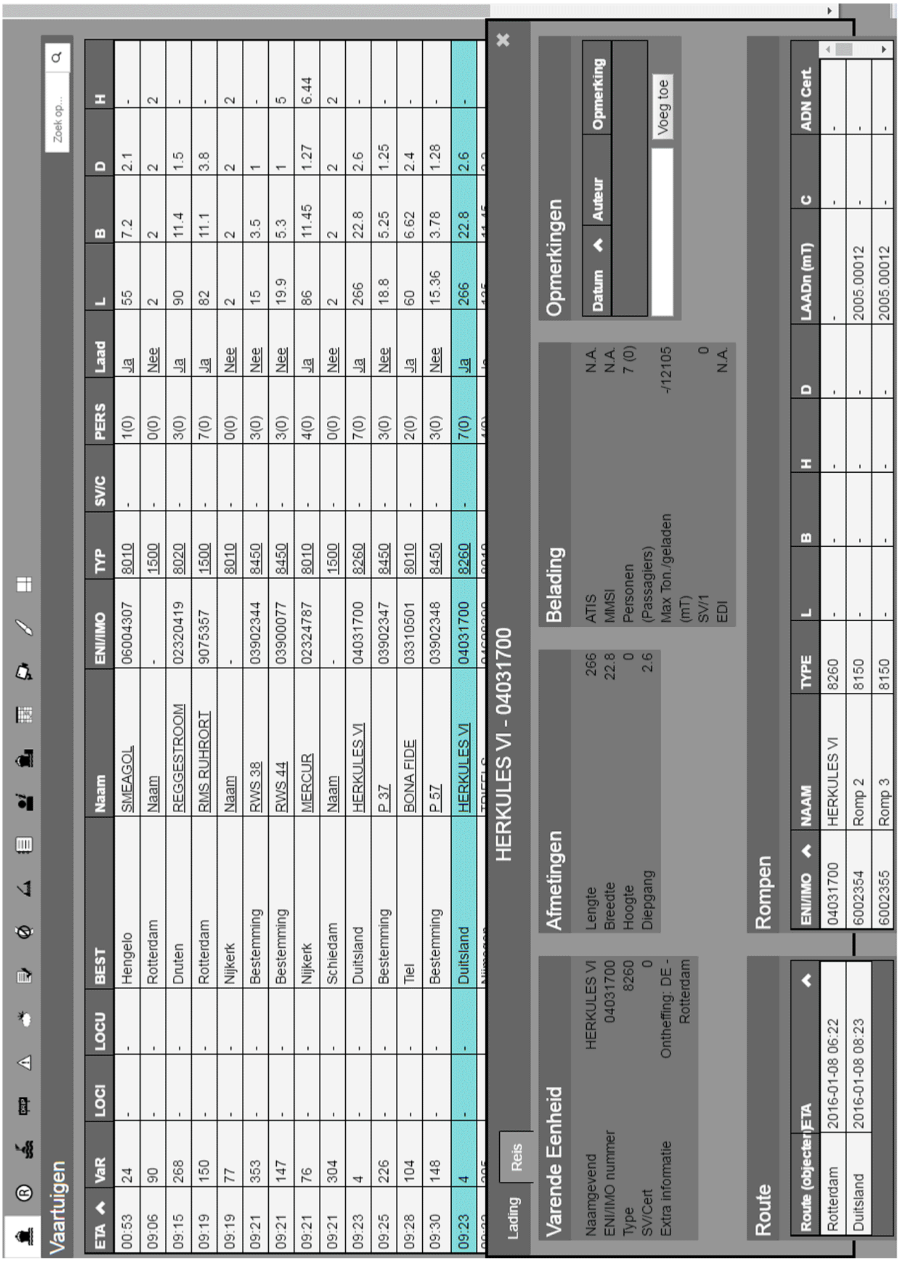
Area of Focus windows of context-dependent adaptable UI



Area of control window of context-dependent adaptable UI



Information overview window and information detail window of coherent, integrated and context-dependent adaptable UI



APPENDIX IX

RAW NASA TASK LOAD INDEX IN DUTCH

Overview of how Raw NASA Task Load Index was translated into Dutch.

Mental Demand	Mentale belasting: Hoeveel mentale en perceptuele activiteit was vereist (bijvoorbeeld: nadenken, bepalen, berekenen, herinneren, bekijken, opzoeken, enz.)? Was de taak gemakkelijk of veeleisende, eenvoudig of complex, moest je zeer zorgvuldig te werk gaan of kon je redelijk nonchalant werken?
Physical Demand	Fysieke belasting: Hoeveel fysieke activiteit was vereist (bijvoorbeeld: duwen, trekken, (lichaam of object) draaien, bedienen (o.a. muis / toetsenbord), activeren, etc.)? Was de taak gemakkelijk of veeleisende, traag of snel, lui of vermoeiende, rustgevende of moeizaam?
Temporal Demand	Tijdsdruk: Hoeveel tijdsdruk heb je gevoeld ten gevolge van het tempo waarin taken of taak elementen zich voordeden? Was het tempo traag en ontspannen of snel en panisch?
Effort	Inspanning: Hoe hard heb je (mentaal en fysiek) moeten werken om zo te presteren als je gedaan hebt?
Performance	Prestaties: Hoe succesvol denk je dat je was in het volbrengen van de operationeel netwerkmanagement doelen en taken die bij dit scenario horen? Hoe tevreden bent je met je eigen presteren? Let op: links staat voor goed en rechts staat voor slecht. Een lagere score betekent dus beter presteren.
Frustration	Frustratie-niveau: Hoe onzeker, ontmoedigd, geïrriteerd, gespannen en geërgerd (frustratie hoog) versus zelfverzekerd, onbezorgd, tevreden, ontspannen en geduldig (frustratie laag) voelde je je tijdens de taak?

APPENDIX X

EXAMPLES OF LOGGED DATA

This appendix gives examples of the kind of data that is logged by the simulator system.

Example of communication log, filter on ID to only show data with ID = 33

Role	Time closing ID	ID	From	To	Type	Text	Exe-cut-ed	Time of execution
Observer	14:37:54	33	Marin	ONM	Start text	Hier de Marin	Yes	14:36:23
Observer	14:37:54	33	Marin	ONM	Obliged	Ik heb gehoord van de stremming bij Culemborg. Kan ik bij sluis Hagestein ligplaats nemen totdat de stremming opgeheven is?	Yes	14:36:23
Observer	14:37:54	33	Marin	ONM	React	Oké, waar kan ik dan wel een ligplaats vinden? (Als gemeld: geen vrije ligplaatsen bij Hagestein)	Yes	14:37:19
Observer	14:37:54	33	Marin	ONM	React	Is er nog wel plek bij de Beatrixsluis? Dan ga ik daar overnachten. (Als gemeld: geen vrije ligplaats Hagestein, geplande stremming Hagestein)	Yes	14:37:23

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Role	Time closing ID	ID	From	To	Type	Text	Exe-cut-ed	Time of execution
Observer	14:37:54	33	Marin	ONM	React	Bedankt, dan overnacht ik bij de Beatrixsluis. (Als gemeld: geen vrije ligplaatsen bij Hagestein, geplande stremming Hagestein en bij Beatrixsluis wel plek)	Yes	14:37:33
Observer	14:37:54	33	Marin	ONM	Extra	Zo goed mogelijk aansluiten. Morgen 8 uur verder.		
Test leader	14:38:04	33	Marin	ONM	Start text	Hier de Marin	Yes	14:36:18
Test leader	14:38:04	33	Marin	ONM	Obliged	Ik heb gehoord van de stremming bij Culemborg. Kan ik bij sluis Hagestein ligplaats nemen totdat de stremming opgeheven is?	Yes	14:36:27
Test leader	14:38:04	33	Marin	ONM	React	Bedankt, dan overnacht ik bij de Beatrixsluis. (Als gemeld: geen vrije ligplaatsen bij Hagestein, geplande stremming Hagestein en bij Beatrixsluis wel plek)	Yes	14:37:41

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Role	**Time closing ID**	**ID**	**From**	**To**	**Type**	**Text**	**Exe-cut-ed**	**Time of execution**
Test leader	14:38:04	33	Marin	ONM	Extra	gevraagd wacht-gegevens!		
Test leader	14:39:36	33	Marin	ONM	React	Ik vaar bij Utrecht, ik ben net voorbij Kanaleneiland.	Yes	14:39:14
Test leader	14:39:36	33	Marin	ONM	Extra	gegevens staan niet in het systeem vraag om deze nog een keer te bicsen.		
Observer	14:39:36	33	Marin	ONM	React	Ik vaar bij Utrecht, ik ben net voorbij Kanaleneiland.	Yes	14:39:11
Observer	14:39:36	33	Marin	ONM	Extra	Niet te vinden, ik meld me opnieuw. Ik zal mijn AIS nakijken. AIS wel gevonden.		

Example of actions log: part of the data in the actions log file of case 4 scenario B

Role	Time	Action	Description	Content action
Test4	14:06:16	Adapt Area of Focus window	AoF window:	(4.551601409912111, 51.7317595303729) x (5.432567596435548, 51.997829088843986)
Test4	14:06:24	Open detail information window	Open details vessel PRESTO	
Test4	14:06:24	Select row in information overview window	Select vessel PRESTO in overview window	

Example of freeze log: image logging selected locations on map by answering SAGAT query 1

Example of freeze log file: query 1 and 2

Query	Option	Var.ID	Answer	Expected answer
1	Fire at Presto	F1CUL001A11	No correct answer. Answer closest to expected answer: vaarweg gestremd ivm brand op schip in Culemborg, 19863,19 meter	Brand aan boord Presto
1	Planned obstruction Hagestein at 17:00 h	F1CUL001A21	No correct answer. Answer closest to expected answer: vaarweg gestremd ivm brand op schip in Culemborg, 25982,21 meter	Geplande stremming Hagestein om 17:00 uur
2	No known incident	F1CUL002A01	No	No
2	8010 Motor cargo	F1CUL002A02	Yes	Yes
2	8020 Motor cargo	F1CUL002A03	No	No
2	8030 Container ship	F1CUL002A04	No	No
2	8040 Gas tank vessel	F1CUL002A05	No	No
2	8090 Motor cargo, pusher	F1CUL002A06	No	No
2	8210 Pusher, one barge	F1CUL002A07	No	No
2	8220 Pusher, two barges	F1CUL002A08	No	No
2	8240 Pusher, four barges	F1CUL002A09	No	No
2	8260 Pusher, six barges	F1CUL002A10	No	No
2	Other	F1CUL002A11	No	No

APPENDIX XI

EXAMPLE OF CODEBOOK USED FOR DATA ANALYSIS

This appendix gives examples of the codebook developed to structure our data analysis.

Codebook example: overview of variables related to the question asked by the skipper of the Marin

Variable ID	Variable name	Variable description	Variable object value	Variable type
B_V4MAR001UIT	Executed?	Marin --> ONM	{0, 1}	Measured
B_V4MAR001A00	Accuracy communication	Marin --> ONM	{0-2, 8, 9}	Calculated
B_K1 MAR001A00	Searched for answer in area of focus map	Marin --> ONM	{0, 1}	Measured
B_V4 MAR001A10	Information provided about available anchorage grounds near lock Beatrix	Marin --> ONM	{1, 0}	Measured
B_V4MAR001A20	Information provided about planned obstruction lock Hagestein	Marin --> ONM	{1, 0}	Measured
B_V4MAR001A30	Information provided about no free anchorage ground near lock Hagestein	Marin --> ONM	{1, 0}	Measured
B_V4MAR001L00	Speed of answering	Marin --> ONM	{0-5400, 8888, 9999}	Calculated
B_V4MAR001T10	Time of question	Marin --> ONM	Date & Time	Measured
B_V4MAR001T20	Time of answer	Marin --> ONM	Date & Time	Measured

Codebook example 2: code for calculation of variables related to question asked by the skipper of Marin

Variable ID	ID in log	Search: Text content in log files	Variable source value	Variable calculation
B_V4MAR 001UIT	33		{Yes, No}	sum("Yes") > 0, than = 1; else: = 0.
B_V4MAR 001A00				if B_K2MAR001A00 = 1, than: highest value of A10, A20, and A30
B_K2MAR 001A00				Calculation if Area of Focus map displayed location of anchorage ground between question skipper and answer operator. "Yes" = 1, "No" = 0.
B_V4MAR 001A10	33	Bedankt, dan overnacht ik bij de Beatrixsluis. (Als gemeld: geen vrije ligplaatsen bij Hagestein, geplande stremming Hagestein en bij Beatrixsluis wel plek)	{Yes, No}	Yes = 2; No =0
B_V4MAR 001A20	33	Bedankt voor de informatie, dan overnacht ik bij Hagestein als ik daar om vijf uur nog niet voorbij ben. (Als gemeld: geplande stremming Hagestein)	{Yes, No}	Yes = 1; No =0
B_V4MAR 001A30	33	Oké, waar kan ik dan wel een ligplaats vinden? (Als gemeld: geen vrije ligplaatsen bij Hagestein)	{Yes, No}	Yes = 1; No =0
B_V4MAR 001L00				V4MAR001T20 - V4MAR001T10
B_V4MAR 001T10	33	Ik heb gehoord van de stremming bij Culemborg. Kan ik bij sluis Hagestein ligplaats nemen totdat de stremming opgeheven is?	Yes: Time	Time displayed in row of first occurrence of "Yes" after specified text content
B_V4MAR 001T20	33	Ja	Yes: Time	Time displayed in row of first occurrence of "Yes" after specified text content

APPENDIX XII

RESULTS OF DATA ANALYSIS EXPERIMENTS

This appendix gives an overview of the data analysis of testing the effect of the UI concepts on operators' SA, task performance, and workload.

Wilcoxon Signed Rank Tests: testing differences between MMI1 and MMI2

Variable	Effect Size	Significance	Effect direction	
SA query 1	-0.17	0.31	MMI 2 < MMI 1	6
			MMI 2 > MMI 1	11
			MMI 2 = MMI 1	1
SA query 1 distance	-0.01	0.94	MMI 2 < MMI 1	9
			MMI 2 > MMI 1	9
			MMI 2 = MMI 1	0
SA query 2	-0.07	0.65	MMI 2 < MMI 1	2
			MMI 2 > MMI 1	2
			MMI 2 = MMI 1	14
SA query 3	0.20	0.24	MMI 2 < MMI 1	1
			MMI 2 > MMI 1	0
			MMI 2 = MMI 1	17
SA query 4	-0.09	0.61	MMI 2 < MMI 1	5
			MMI 2 > MMI 1	2
			MMI 2 = MMI 1	11
SA query 5	-0.11	0.49	MMI 2 < MMI 1	1
			MMI 2 > MMI 1	2
			MMI 2 = MMI 1	15
SA query 6	-0.00	1.00	MMI 2 = MMI 1	18
SA query 7	-0.07	0.67	MMI 2 < MMI 1	6
			MMI 2 > MMI 1	4
			MMI 2 = MMI 1	8
SA query 8	-0.11	0.50	MMI 2 < MMI 1	7
			MMI 2 > MMI 1	10
			MMI 2 = MMI 1	1
SA query 9	-0.05	0.74	MMI 2 < MMI 1	5
			MMI 2 > MMI 1	5
			MMI 2 = MMI 1	8

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Continuation from previous page				
Variable	**Effect Size**	**Significance**	**Effect direction**	
SA query 10	-0.29	0.08	MMI 2 < MMI 1	4
			MMI 2 > MMI 1	12
			MMI 2 = MMI 1	2
SA query 11	-0.52	0.00	MMI 2 < MMI 1	11
			MMI 2 > MMI 1	4
			MMI 2 = MMI 1	3
SA query 12	-0.04	0.82	MMI 2 < MMI 1	8
			MMI 2 > MMI 1	6
			MMI 2 = MMI 1	4
SA query 13	-0.10	0.57	MMI 2 < MMI 1	5
			MMI 2 > MMI 1	7
			MMI 2 = MMI 1	6
SA query 14	-0.16	0.34	MMI 2 < MMI 1	5
			MMI 2 > MMI 1	7
			MMI 2 = MMI 1	6
Time AoF correct	-0.34	0.04	MMI 2 < MMI 1	12
			MMI 2 > MMI 1	6
			MMI 2 = MMI 1	0
Time detail info window open	-0.22	0.19	MMI 2 < MMI 1	9
			MMI 2 > MMI 1	5
			MMI 2 = MMI 1	0
Count detail info window open	-0.20	0.24	MMI 2 < MMI 1	1
			MMI 2 > MMI 1	3
			MMI 2 = MMI 1	14
Time anchorage question	-0.12	0.48	MMI 2 < MMI 1	7
			MMI 2 > MMI 1	10
			MMI 2 = MMI 1	1
Count report incident VHF	-0.37	0.03	MMI 2 < MMI 1	1
			MMI 2 > MMI 1	6
			MMI 2 = MMI 1	11
Time report incident VHF	-0.25	0.13	MMI 2 < MMI 1	3
			MMI 2 > MMI 1	7
			MMI 2 = MMI 1	0
Count set measures	-0.34	0.04	MMI 2 < MMI 1	3
			MMI 2 > MMI 1	0
			MMI 2 = MMI 1	15
Continues on next page				

Continuation from previous page				
Variable	**Effect Size**	**Significance**	**Effect direction**	
Time set measures	-0.02	0.89	MMI 2 < MMI 1	8
			MMI 2 > MMI 1	7
			MMI 2 = MMI 1	0
Count end incident VHF	-0.20	0.24	MMI 2 < MMI 1	3
			MMI 2 > MMI 1	1
			MMI 2 = MMI 1	14
Count lift measures	-0.37	0.03	MMI 2 < MMI 1	6
			MMI 2 > MMI 1	1
			MMI 2 = MMI 1	11
Time communication	-0.44	0.01	MMI 2 < MMI 1	12
			MMI 2 > MMI 1	6
			MMI 2 = MMI 1	0
Total amount of priority 1 actions executed	-0.27	0.10	MMI 2 < MMI 1	5
			MMI 2 > MMI 1	12
			MMI 2 = MMI 1	1
Total amount of priority 2 actions executed	-0.00	0.98	MMI 2 < MMI 1	10
			MMI 2 > MMI 1	8
			MMI 2 = MMI 1	0
Total amount of actions executed	-0.15	0.37	MMI 2 < MMI 1	7
			MMI 2 > MMI 1	11
			MMI 2 = MMI 1	0
Accuracy answers questions skippers	-0.19	0.26	MMI 2 < MMI 1	6
			MMI 2 > MMI 1	10
			MMI 2 = MMI 1	2
Accuracy total of required actions	-0.23	0.17	MMI 2 < MMI 1	12
			MMI 2 > MMI 1	6
			MMI 2 = MMI 1	0
Accuracy answer skippers questions requiring Level 1 SA knowledge	-0.07	0.65	MMI 2 < MMI 1	2
			MMI 2 > MMI 1	2
			MMI 2 = MMI 1	14
Accuracy answer skippers questions requiring Level 2 SA knowledge	-0.03	0.87	MMI 2 < MMI 1	3
			MMI 2 > MMI 1	2
			MMI 2 = MMI 1	13
Accuracy answer skippers questions requiring Level 3 SA knowledge	-0.13	0.44	MMI 2 < MMI 1	5
			MMI 2 > MMI 1	8
			MMI 2 = MMI 1	2
Continues on next page				

Continuation from previous page				
Variable	**Effect Size**	**Significance**	**Effect direction**	
Accuracy order of Actions	-0.32	0.03	MMI 2 < MMI 1	5
			MMI 2 > MMI1	9
			MMI 2 = MMI 1	4
RTLX Freeze 1	-0.12	0.47	MMI 2 < MMI 1	7
			MMI 2 > MMI 1	11
			MMI 2 = MMI 1	0
RTLX Freeze 2	-0.15	0.37	MMI 2 < MMI 1	8
			MMI 2 > MMI 1	10
			MMI 2 = MMI 1	0
RTLX Freeze 3	-0.04	0.80	MMI 2 < MMI 1	8
			MMI 2 > MMI 1	9
			MMI 2 = MMI 1	0
RTLX Average	-0.07	0.67	MMI 2 < MMI 1	9
			MMI 2 > MMI 1	8
			MMI 2 = MMI 1	0

Wilcoxon Signed Rank Tests: testing differences between MMI1 and MMI3

Variable	Effect Size	Significance	Effect direction	
SA query 1	-0.05	0.41	MMI 3 < MMI 1	6
			MMI 3 > MMI 1	6
			MMI 3 = MMI 1	0
SA query 1 distance	-0.11	0.29	MMI 3 < MMI 1	5
			MMI 3 > MMI 1	7
			MMI 3 = MMI 1	0
SA query 2	-0.27	0.09	MMI 3 < MMI 1	4
			MMI 3 > MMI 1	1
			MMI 3 = MMI 1	7
SA query 3	-0.42	0.02	MMI 3 < MMI 1	3
			MMI 3 > MMI 1	0
			MMI 3 = MMI 1	9
SA query 4	-0.52	0.01	MMI 3 < MMI 1	6
			MMI 3 > MMI 1	1
			MMI 3 = MMI 1	5
SA query 5	-0.24	0.12	MMI 3 < MMI 1	0
			MMI 3 > MMI 1	1
			MMI 3 = MMI 1	11
SA query 6	-0.00	0.50	MMI 3 = MMI 1	12
Continues on next page				

Continuation from previous page				
Variable	**Effect Size**	**Significance**	**Effect direction**	
SA query 7	-0.00	0.50	MMI 3 < MMI 1	1
			MMI 3 > MMI 1	2
			MMI 3 = MMI 1	9
SA query 8	-0.10	0.32	MMI 3 < MMI 1	6
			MMI 3 > MMI 1	5
			MMI 3 = MMI 1	1
SA query 9	-0.08	0.35	MMI 3 < MMI 1	3
			MMI 3 > MMI 1	3
			MMI 3 = MMI 1	6
SA query 10	-0.19	0.18	MMI 3 < MMI 1	3
			MMI 3 > MMI 1	5
			MMI 3 = MMI 1	4
SA query 11	-0.31	0.06	MMI 3 < MMI 1	5
			MMI 3 > MMI 1	3
			MMI 3 = MMI 1	4
SA query 12	-0.33	0.05	MMI 3 < MMI 1	6
			MMI 3 > MMI 1	2
			MMI 3 = MMI 1	4
SA query 13	-0.38	0.03	MMI 3 < MMI 1	6
			MMI 3 > MMI 1	3
			MMI 3 = MMI 1	3
SA query 14	-0.00	0.50	MMI 3 < MMI 1	4
			MMI 3 > MMI 1	3
			MMI 3 = MMI 1	5
Time AoF correct	-0.02	0.46	MMI 3 < MMI 1	4
			MMI 3 > MMI 1	8
			MMI 3 = MMI 1	0
Time detail info window open	-0.38	0.03	MMI 3 < MMI 1	3
			MMI 3 > MMI 1	7
			MMI 3 = MMI 1	0
Count detail info window open	-0.34	0.05	MMI 3 < MMI 1	0
			MMI 3 > MMI 1	2
			MMI 3 = MMI 1	10
Time anchorage question	-0.10	0.32	MMI 3 < MMI 1	5
			MMI 3 > MMI 1	7
			MMI 3 = MMI 1	0
Continues on next page				

Continuation from previous page

Variable	Effect Size	Significance	Effect direction	
Count report incident VHF	-0.24	0.12	MMI 3 < MMI 1	1
			MMI 3 > MMI 1	3
			MMI 3 = MMI 1	8
Time report incident VHF	-0.30	0.07	MMI 3 < MMI 1	2
			MMI 3 > MMI 1	6
			MMI 3 = MMI 1	0
Count set measures	-0.42	0.02	MMI 3 < MMI 1	3
			MMI 3 > MMI 1	0
			MMI 3 = MMI 1	9
Time set measures	-0.27	0.09	MMI 3 < MMI 1	4
			MMI 3 > MMI 1	5
			MMI 3 = MMI 1	0
Count end incident VHF	-0.00	0.50	MMI 3 < MMI 1	1
			MMI 3 > MMI 1	1
			MMI 3 = MMI 1	10
Count lift measures	-0.20	0.17	MMI 3 < MMI 1	4
			MMI 3 > MMI 1	2
			MMI 3 = MMI 1	6
Time communication	-0.19	0.18	MMI 3 < MMI 1	8
			MMI 3 > MMI 1	4
			MMI 3 = MMI 1	0
Total amount of priority 1 actions executed	-0.04	0.43	MMI 3 < MMI 1	7
			MMI 3 > MMI 1	5
			MMI 3 = MMI 1	0
Total amount of priority 2 actions executed	-0.09	0.32	MMI 3 < MMI 1	8
			MMI 3 > MMI 1	4
			MMI 3 = MMI 1	0
Total amount of actions executed	-0.13	0.26	MMI 3 < MMI 1	6
			MMI 3 > MMI 1	6
			MMI 3 = MMI 1	0
Accuracy answers questions skippers	-0.15	0.23	MMI 3 < MMI 1	3
			MMI 3 > MMI 1	8
			MMI 3 = MMI 1	1
Accuracy total of required actions	-0.21	0.15	MMI 3 < MMI 1	7
			MMI 3 > MMI 1	5
			MMI 3 = MMI 1	0

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Continuation from previous page				
Variable	**Effect Size**	**Significance**	**Effect direction**	
Accuracy answer skippers questions requiring Level 1 SA knowledge	-0.24	0.12	MMI 3 < MMI 1	1
			MMI 3 > MMI 1	0
			MMI 3 = MMI 1	10
Accuracy answer skippers questions requiring Level 2 SA knowledge	-0.09	0.33	MMI 3 < MMI 1	2
			MMI 3 > MMI 1	2
			MMI 3 = MMI 1	8
Accuracy answer skippers questions requiring Level 3 SA knowledge	-0.33	0.05	MMI 3 < MMI 1	4
			MMI 3 > MMI 1	5
			MMI 3 = MMI 1	3
Accuracy order of Actions	-0.25	0.12	MMI 3 < MMI 1	3
			MMI 3 > MMI1	8
			MMI 3 = MMI 1	1
RTLX Freeze 1	-.022	0.15	MMI 3 < MMI 1	5
			MMI 3 > MMI 1	6
			MMI 3 = MMI 1	1
RTLX Freeze 2	-0.02	0.46	MMI 3 < MMI 1	5
			MMI 3 > MMI 1	7
			MMI 3 = MMI 1	0
RTLX Freeze 3	-0.10	0.30	MMI 3 < MMI 1	5
			MMI 3 > MMI 1	7
			MMI 3 = MMI 1	0
RTLX Average	-0.06	0.39	MMI 3 < MMI 1	5
			MMI 3 > MMI 1	7
			MMI 3 = MMI 1	0

About the author

ABOUT THE AUTHOR

Ellen Corine (Ellemieke) van Doorn (born May 17th, 1984 in Vlissingen, the Netherlands) received her secondary education (VWO) at the Christelijke Scholengemeenschap Walcheren in Middelburg from 1996 to 2002. She started her University education at the Faculty of Industrial Design Engineering at Delft University of Technology in 2002. In 2004 the TU Delft introduced the Bachelor / Master program. Ellemieke finished the courses that correspond to the Bachelor before the new program was fully introduced. In 2006 she enrolled in the Master Design for Interaction at the same Faculty. In 2007 she received the Bachelor degree. She completed her Master in 2008. Her graduation project was entitled “Designing the digital design studio of the Future”. Based on this work, she wrote an article[2] which she presented at ICED’09 and was rewarded as Reviewers’ favorite.

In 2008 Ellemieke started to work as traffic control engineering advisor at the Green Wave Team of Rijkswaterstaat. As part of this job, from 2009 till 2011 she was project manager of Silver Road Design; an innovation project on elderly friendly road design. In this role she was also the chairman of the CROW workgroup Elderly and Infrastructure, which published national guidelines for elderly friendly road design. In 2011 Ellemieke started as senior advisor at the Traffic Management Systems Business Analyst department of Rijkswaterstaat. She is the human factors and man-machine interaction specialist for all main traffic management systems and innovation projects related to traffic management control room workplace design. In this role she was a work package leader in the Vessel Traffic Management Centre of Tomorrow innovation project. In the project, she was responsible for the workstation and man-machine interaction design. She initiated her PhD

[2] Doorn, van E.C., Horvath, I., “Use scenarios for digital design studios of the future”, in Proceedings of ICED’09, August 24 – 27, 2009, Stanford, CA, USA

research, which has its roots in the Vessel Traffic Management Centre of Tomorrow innovation project, in 2012. As part of this research, she acted as product owner and research leader in the development of and use of a traffic management workplace simulator.

In her free time, Ellemieke is the 3rd trombonist of the all ladies Big Band Duchess of Swing. As text writer and graphic designer, she is responsible for the band's public relations and social media. In 2016 she organized the jubilee concert "A tribute to Glenn Miller". Currently, the band is preparing a third visit to D-Day commemorations in Normandy, France. Since 2012, Ellemieke is active in her local community as street-contact person and by coordinating a citizens' initiative to maintain approximately 500 m^2 green area in a ca. 9000 m^2 park. Besides, she enjoys family life with Paul and their children Okke and Berit.

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