A SYSTEMATIC APPROACH TO ADDRESSING THE INFLUENCE OF MAN-MACHINE INTERACTION ON SITUATION AWARENESS

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ABSTRACT
This paper presents a systematic approach towards the study of required situation awareness (RSA) in traffic management context. Current theories are not suitable to clearly define the RSA in complex man-machine interaction (MMI) contexts. Deficiencies of man-machine interaction are difficult to recognize and resolve. This paper analyzes: (i) how the individual, task and system factors define the MMI, (ii) how the MMI and information needs influence the assessment of situation awareness (SA), and (iii) what influence they together have on the required situation awareness. This paper presents a structured analysis scheme, developed to gain more holistic body of knowledge about SA. This scheme was applied in traffic management context to structure cognitive task analysis sessions and to gain insight in SA in complex MMI context. It helps to better understand which information needed by the operator is part of SA, and which information needs to be available, but will not be part of operator’s SA. Future research will focus on developing interface solutions for an awareness-enhancing informing.

KEYWORDS
Required situation awareness, man-machine interaction, information processing, analysis scheme, applied cognitive task analysis, traffic management

1. INTRODUCTION
In nautical traffic management centers, operators need accurate situation awareness (SA) to enable correct and in-time decision making and action performance to support safe and efficient traffic flows in the dynamic traffic environment. To acquire and maintain SA, operators simultaneously deal with several different information systems. In the practical work of Rijkswaterstaat (the executive body of the Dutch Ministry of Infrastructure and Environment) it has been observed that the lack of SA, that occurs due to the increase of the complexity of the traffic management practice, the related number of operating systems, and the amount of related data, as well as due to the growth of critical traffic situations, implies a higher risk in decision making [1]. In order to overcome these new challenges of traffic management, we aim to identify and resolve deficiencies of current man-machine interactions (MMI).

Within different divisions of Rijkswaterstaat, operators are responsible for nautical operational network management. They control events and incidents in a region and provide relevant information about the situation within the region to skippers, colleagues and emergency services. Rijkswaterstaat aims to improve and equalize working methods and responsibilities of nautical operational network management (ONM) tasks and to redesign the MMI to optimize task performance. To do so, they need to define the required situation awareness (RSA) of ONM operators. Operators and subject-matter experts were asked to provide information about their RSA. However, defining the RSA of ONM tasks proved to be complex and the created descriptions remained vague. Instead of describing the knowledge necessary to be memorized about the dynamic environment, they mainly mention the importance of the different information systems used. They could not distinguish important SA
knowledge from other relevant information. A more structured approach is needed in order to develop a more comprehensive and generally acceptable description of the RSA for ONM tasks.

Current theories address SA as if the RSA knowledge is static for a specific task, independent of context factors such as the used man-machine interface. 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 [2]. 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 RSA however is often difficult to define.

The hypothesis considered in this research is that the process of information processing and the context of tasks influence the required situation awareness. Imagine two operators, working with different man-machine interfaces. In case of a breakdown of a sluice, they on request need to inform others about the queue time of another sluice. Thus skippers can choose to take a different route. Imagine a man-machine interface which only displays a list of ships and the coordinates of their position on the waterway. Which such a system, it is mentally demanding for an operator to decide upon the queue time of sluices. It will take too long to recalculate this each time when someone requests this information. This means queue time is part of his required situation awareness knowledge. For an operator using a system which automatically displays the queue time of sluices, looking for this information is not demanding and takes a short time. Due to the moderate effort it takes to access this knowledge, he most likely will use a different information processing strategy and the knowledge is less likely to be part of the operator’s SA. This however does not mean that this operator has a lack of situation awareness. The difference in man-machine interface influenced the required situation awareness knowledge. Since the different aspects of SA are interrelated, a structured approach aiming for more holistic knowledge will help to overcome these limitations.

The essence of a holistic understanding is the comprehension of the relations between the different aspects. In this paper, the relations are structured into an analysis scheme to support our aim to identify and resolve deficiencies of current man-machine interactions in traffic management context.

Context significantly influences SA. Most literature on SA however addresses it from aviation, air traffic control and process control perspective, not from nautical traffic management point of view. This paper argues that in essence the traffic management context is similar to those contexts used to develop current theories. It reviews the existing theories from analogue contexts to form the basis of a structured approach to situation awareness in traffic management context. Besides the more commonly discussed aspects of level of knowledge and the assessment process, it will take into consideration theories addressing the influence of context factors, like the used man-machine interface, on situation awareness.

To verify the hypothesis and the developed analysis scheme, we used it to study the RSA for nautical operational network management tasks. This paper presents the lessons learnt and discusses the verification and validation of the analysis scheme. It reflects to what extent this contribution helps researchers studying situation awareness in complex man-machine interaction situations.

2. SITUATION AWARENESS IN TRAFFIC MANAGEMENT AND ANALOGUE CONTEXTS

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 [3][4][5], air traffic control [6][7], process control [8][9] and traffic operations [10][11]. In the fields of aviation, air traffic control, and process control various theories of situation awareness have been developed. Although SA plays an important role in traffic management, it has not been sufficiently addressed so far from either a theoretical, or a practical perspective.

In the fields of aviation and air traffic control, 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 [5][7]. Consequently, as Endsley concludes, operators are dependent on an on-going up-to-date analysis of the environment [12].
In nautical traffic management, situations evolve due to skipper’s actions and environmental factors like weather conditions. Traffic management operators influence the situation by providing information to the skippers and through traffic management measures. Both skippers and weather conditions are unpredictable. An on-going analysis of the environment thus is necessary in traffic management context as well.

A second important characteristic of an aviation and air traffic control environment is that operators working in these environments typically pursue multiple goals simultaneously. To do so, they need to carry out multiple tasks, which require time-constrained decisions and actions [12]. SA is the foundation for their decision making and actions [13]. Kaber and Endsley argue that process control and aviation share these characteristics [8]. Operators in traffic management control environments are responsible for safe water levels, safe traffic situations and efficient traffic flows. These three main goals cannot be addressed separately, as they influence each other. Time-constrained measures to ensure safe water levels, like limiting the use of locks, can have a negative effect on safe and efficient traffic flows.

Due to the above mentioned similarities, aviation, air traffic control and process control are considered analogue contexts to nautical traffic management. Theories relevant to these contexts are taken into consideration.

Endsley’s theory, published in 1995, is by far the most commonly used theory of situation awareness in these analogue contexts [14][15][16]. Endsley uses the following definition: “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” [12]. Although this definition implies a process viewpoint, describing the process of SA assessment, the work presented by Endsley describes the SA knowledge, not the assessment process. In her work, the distinction between these two aspects of SA is unclear. Although understanding the difference is important, this more general description makes Endsley’s theory suitable not only to discuss the level of knowledge, but also the assessment process. Indeed, influential articles on SA theories, including those addressing the assessment and context aspects, refer back to Endsley’s theory.

To understand the multifaceted challenges of the study of SA in traffic management and analogue contexts, this paper first addresses the different aspects separately, before discussing their relations.

2.1. Situation awareness knowledge
Operator’s situation awareness knowledge is the memorized knowledge associated with the state of the dynamic environment. Information which is used by the operator, but not committed to memory, is part of an operator’s information needs, but not relevant to his SA knowledge. It is important to distinguish operator’s SA knowledge from required situation awareness. RSA is the knowledge needed by the operator to commit tasks necessary to fulfill operator’s objectives. If an operator fails to memorize the knowledge required to perform his tasks efficiently, effectively and in a timely manner to reach the job related goals, he has a lack of situation awareness.

As discussed in this paper, both the SA knowledge and the RSA are influenced by both the SA assessment process and the context, including operator’s goals, tasks and information needs as well as the man-machine interactions.

To simplify and structure the study of SA knowledge and the RSA, the distinction in levels of SA, as proposed by Endsley, is used [12]:
- Perceptual knowledge: the cognitively unprocessed knowledge of elements in the current situation.
- Comprehended knowledge: a deeper understanding of the meaning and relationships of knowledge in the current situation.
- Projected knowledge: insight in future activities of the elements in the environment and understanding of future environment dynamics in relation to operator’s goals.

2.2. Situation awareness assessment
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 [17].
- 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.

- He combines the perceived disjoined information, for comprehension of the current situation.
- He 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.

As visualized by Endsley in her model of SA in dynamic decision making, see Figure 1, individual, task and system factors influence an operator’s SA knowledge. Durso and Sethumadhavan and Adams et al. point out that a person’s SA is influenced by attention and working memory capacity, which are partly innate but can be trained [2] [18]. 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 argue 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 [19]. These contributions point out individual factors do not directly influence SA knowledge, but have effect on the SA assessment. As such, these factors indirectly influence SA knowledge.

By addressing the individual factors separate from other influential factors, these theories however overlook the importance of man-machine interaction. As argued earlier in this paper, man-machine interaction influences the information processing strategies of operators. Different information processing strategies can result in differences in RSA knowledge. Individual characteristics, like 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 and Wickens discuss how a higher task complexity, in the case of which the number of goals, tasks and decisions to be made grow, will increase the amount of mental workload required to achieve SA [5] [12]. They consider a high mental workload as a stressor, which can negatively affect the SA assessment, while low mental workload can lead to vigilance problems. Endsley argues that stress will negatively influence an operator’s assessment process as he will tend to (i) arrive at a decision, without exploring all information available, (ii) put more attention to negative information and (iii) have a more scattered and poorly organized scanning of stimuli [12]. Endsley states that stress reduces working memory capacity and retrieval of information. Although we see the relevance of taking into consideration task factors when studying SA, addressing task factors like stress, workload and complexity isolated from other aspects will not give insight in the effect these have on the operator’s situation awareness knowledge. In the Rijkswaterstaat practice, changes in tasks often result in changes in the systems used by the operator. The effect on SA significantly differs depending on how these systems change. It is our hypothesis that when simply more information systems are added to the operator’s workplace, this will have a different impact then when the total of systems used by the operator are redesigned to optimally support the changed demands on goals, tasks and decisions to be made.

Endsley argues 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 [12]. As such, Endsley takes individual factors like information processing into consideration when discussing system factors influencing SA. Completeness and correctness of data and the interface design used to present this data influence the SA assessment. Goossens et al. [20] and Essendorfer et al. [21] propose to reduce the effort required for comprehension of the current situation by integrated data presentation. Automated feedback on planned changes is suggested to support projected SA knowledge [20]. How these aspects influence SA however remains unclear. More insights are needed, especially in how interface design influences information processing for SA assessment. Although it might be possible to distract some general rules, it is our hypothesis that this will be dependent on individual and task factors as well.

2.3. Context of situation awareness

Smith and Hancock define SA as the invariant defining what must be known and done to fulfill the operator’s goal [22]. They regard knowledge about the environment and the directed action within that environment as products of SA. Their definition describes what in our theory is called the required situation awareness. They exclude SA knowledge and the assessment process from their definition of SA. Although this narrow definition is not in line with our strive for a holistic approach, their view remains valuable. Smith and Hancock state that until an external goal and criteria for achieving SA are specified, examination of higher of lower degrees of SA or loss of SA remains impossible [22]. 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.

The theory presented in this paper adopts Smith and Hancock’s suggestion to study the operator’s goals, tasks and information needs in order to define the RSA. These factors alone however do not sufficiently define the influence of context on RSA. Besides information needs, it is the MMI, the interaction between goals, tasks, individual factors and system factors, which influences RSA. This is in line with suggestions of other authors. Stanton et al. propose 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 [23] [24]. However, they refer to both the information contained by the technical systems and the information of the human operators as situation awareness. This creates unnecessary confusion. This paper 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. point out, a distinction must be made between the operator’s RSA knowledge and the display-based information. RSA knowledge is information which must be remembered and updated.
Display-based information can be searched for when needed and forgotten [6]. 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 [19].

Combining the insights from Mogford et al., Patrick and Morgan, and Stanton et al., we propose that allocation of information and the resulting man-machine interaction influence the SA assessment process and resulting memorized knowledge, as well as the operator’s RSA. 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 SA, and (iii) information derived from the system which is part of an operator’s situation awareness.

3. STRUCTURED ANALYSIS SCHEME TO STUDY SITUATION AWARENESS

This paper discusses the multifaceted aspects of situation awareness. To define the required aspects of man-machine interactions to support SA, these different aspects and their relations need to be taken into account. As the cited literature addresses these different aspects in separation from each other, no structured approach towards a more holistic understanding of SA is available. That was the motivation behind our effort to develop a comprehensive analysis scheme that can support achieving this goal. The developed analysis scheme enforces a systematic and structured study of the RSA, see Figure 2. This scheme places the different aspects in logical relationships that are needed to define required situation awareness in case of complex MMI.

This analysis scheme differs from existing theories on SA in that it concurrently considers the three influential factors of SA, namely: (i) individual factors, (ii) system factors, and (iii) task factors, as factors influencing the MMI. Additionally, MMI is considered to influence the SA assessment, which modifies the operator’s SA knowledge. Both the assessment process and the information needs influence the RSA.

The starting points of processing the analysis scheme are the operator’s goals and tasks. They define the information necessary to successfully perform the tasks at hand, and direct the man-machine interactions used to perform these tasks. The individual factors and system factors will influence the resulting MMI.

The MMI and information needs together result in an allocation of information between operator and system. This directs the information processing strategies used for SA assessment. The information processing strategies, like memory-based or display-based strategies, used for assessment will modify the RSA. Information used by the system, not displayed to the operator, will not be part of the operator’s SA. Neither will information belonging to display-based information processing strategies. The MMI design thus can significantly reduce the operator’s RSA.
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 RSA.

4. ANALYSIS SCHEME APPLIED IN TRAFFIC MANAGEMENT CONTEXT

We applied our analysis scheme to study operator’s RSA for ONM tasks. As proposed by the scheme, we started the analysis with a study of the goals and the tasks. This study followed the methodology of Applied Cognitive Task Analysis (ACTA) proposed by Militello et al. [25] and Militello and Hutton [26], extended with activities to investigate information needs and man-machine interaction.

In line with ACTA, we constructed a task diagram to get an overview of the ONM tasks. Altogether, 22 operators individually ranked the error probability and the mental workload of the cognitive tasks to identify difficult cognitive elements. In addition, interviews with eight subject-matter experts were conducted and a study of documentation of the systems used in ONM tasks was used to identify information needs per task.

The ACTA methodology proposes to use knowledge audit interviews to capture aspects of expertise when the relevant tasks have been identified. A knowledge audit involves questions regarding the cues and strategies operators use and questions about experienced difficulties. The participating 22 operators have been divided into two sessions of our extended knowledge audit. Interview questions were developed using expertise probes proposed by Militello et al., like questions about “past & future”, “equipment” and “anomaly” [25]. The generated task diagram and overview of information needs were available to the operators during the knowledge audit session.

In addition to the questions proposed by Militello et al. [25], the knowledge audit included questions to discuss the allocation of information and the use of display-based and memory-based information processing strategies:

- What information do you need to monitor?
- 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? How do you deal with these?

Besides these general questions, operators were asked to individually rank the identified information needs for the most demanding cognitive tasks on two aspects on a scale of 1 (not important) to 5 (very important):

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

The cognitive task analysis ended with simulation interviews. In a simulation interview, operators are asked what they would do in the generated simulated situations. A total of 46 operators were involved in a simulation interview and two different simulated situations were used:

- A skipper reports a collision of a ship carrying dangerous cargo with another ship. The reporting skipper is not involved in the incident. The incident is outside a VTS sector, within the ONM area.
- An operator operating the Bernard sluice reports an unexpectedly obstruction due to a technical failure. The operator indicates that it is forecasted to take 6 hours to repair.

In line with the questions proposed by Militello and al., operators were asked to reflect on: (i) situation assessment, (ii) relevant actions, (iii) critical cues, (iv) alternative ways to interpret, and (v) potential errors [25]. Additionally, information processing strategies were discussed. As they had a hard time to recall information processing strategies when asked individually, the simulation interviews were conducted in pairs (22 operators) and groups of four operators (24 operators). In discussion with each other, they were better able to recall information processing strategies. Extra questions asked about the situation assessment were:

- Which information would you request from others?
- Which information would you search for in your information systems?
- Which information would you use, which is already part of your situation awareness?
- Are there alternative ways in which you could assess the situation?
While operators and subject-matter experts experienced difficulty in directly describing their RSA, all operators were able to provide valuable response to the different steps as described above. 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 RSA, and which information is relevant but not part of RSA.

Combining the insights from all interviews, we developed a comprehensive description of RSA for 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 and three subject-matter experts, who confirmed our view on the required situation awareness and the related information processing strategies used.

A next step in the analysis of RSA to improve the MMI is to study deficiencies of current MMI in practice. To efficiently study current practice, researchers need to know what to study. The information on RSA and related information processing strategies gathered through sessions following the analysis scheme is used to generate an observer checklist, observer evaluation form and self-rating evaluation form. These forms were used in a follow-up research, studying the ONM situation awareness knowledge and deficiencies of current man-machine interfaces in situation awareness support.

5. JUSTIFICATION AND VALIDATION OF OUR ANALYSIS SCHEME

The goal of this research was to develop an analysis scheme to structure the study of required situation awareness in complex dynamic environments in which man-machine interactions play an important role to support operator’s SA. The analysis scheme does not only point out relevant aspects of SA, but emphasizes the relationships between these aspects. For the analysis scheme to be valuable and valid, it needs to be applicable in real-life research to gain insight in RSA in complex MMI context.

5.1. 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. As introduced in Sub-section 2.2 and discussed in Section 3, 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 depicted in Figure 2. As visualized in Figure 3, the different sub-theories used are all built upon Endsley’s theory [12]. They focus on various specific aspects of this theory, without conflicting with it. However, they do add new insights to Endsley’s theory. The used partial theories are reasonably and comprehensively tested theories. The derived components therefore stand logical scrutiny in themselves. 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-

Figure 3  The overall epistemological process of combining existing and tested theories in the analysis scheme
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, 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 study of situation awareness by others, the analysis of both the goals and the tasks of the operators, has been considered a logical first step [27] [28] [29]. Only with information on the goals and tasks, as well as about the individual factors and the system factors, we can understand the man-machine interactions. 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: During the project, the proposed analysis scheme has been operationalized in the practice. Without a structured approach, Rijkswaterstaat was not able to clearly define the operational network management RSA. Using the analysis scheme, Rijkswaterstaat could generate a description of RSA for ONM tasks, which was considered logical and valid by both operators and subject-matter experts. Application of the analysis scheme in a nautical traffic management case study showed positive empirical results. The case study showed the proposed order of steps is suitable to define RSA. The gained insight in RSA 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 the scheme was implementable in practice and helped in the study of deficiencies of current MMI. Therefore, imposing the principle of reasoning with consequences, we may claim that if the proposed analysis scheme works well in practice, there is no reason to assume that the knowledge included in the analysis scheme is not proper or illogical.

5.2. Validation of the conduct and the findings of the research

The aim of this research was to develop an analysis scheme suitable to support the study of SA in complex MMI contexts. The goal was to support researchers to define the RSA to enable them to identify and resolve deficiencies of current man-machine interactions.

First of all, the developed analysis scheme proposes to concurrently analyze the task-, individual-, and system-related factors in their MMI relation. Prior to the interviews based on our analysis scheme, operators in our case study mainly referred to the importance of the used different information systems when asked about their RSA. Systematically analyzing their tasks in relation to the systems helped them to identify information needs per tasks. Discussing individual factors like the difference between experts and novices assisted the discussion about successful information processing strategies. Our case study showed that addressing the different influential factors and their relationships simultaneously helped operators to recall more information than when addressing them separately.

The analysis scheme suggests to explicitly define the information needs per task and to relate the information needs to MMI and information processing strategies which direct SA assessment. In our case study, operators regularly discussed the list of information needs per tasks during the knowledge audit and simulation interviews. Prior to the interviews, operators referred to all information in the available systems as highly relevant. After the interviews, they agreed on a distinction in information which at all times needs to be part of their SA knowledge, and information relevant for specific tasks, which after usage can be forgotten. It resulted in a better understanding of why certain information will be memorized and thus is part of SA, and why certain information is relevant, but will not be part of operator’s SA. The approach also highlighted the difference between experienced operators and novices. Experienced operators better
know the waterways and ships. For instance, due to the clear expectations about cargo and destination, they memorize this information more easily, than novice operators. Since recalling all information takes more effort for novices, they more often use display-based information processing strategies where experts use memory-based strategies. Our case study showed that, by paying attention to information needs explicitly, discussion about MMI and information processing strategies generated insight in the decision making of the operators, their potential errors, and mental workload. It helped operators to gain insights in SA assessment.

We used all the information provided by the operators and subject-matter experts in our extended applied cognitive task analysis to define the RSA for ONM tasks. Following the analysis scheme, we defined RSA by addressing the information needs per task, taking into consideration the discussed SA assessment. If the SA assessment indicated necessary information is part of display-based information processing strategies, it was not part of our RSA description. We presented the resulting RSA description to the operators and subject-matter experts involved in the interviews. They reflected that the gained insight in the RSA corresponds to their view on the reality. The described RSA was found to be logical and valid.

6. DISCUSSION

In order to identify and resolve the deficiencies of current man-machine interactions in nautical traffic management context, we aimed to define the required situation awareness. Current theories however insufficiently support the definition of RSA in complex MMI context. Besides, they do not consider the different aspects influencing SA simultaneously. To overcome these limitations, our main objective was to develop a structured approach to gain more holistic knowledge of SA.

The analysis scheme presented in this paper proposes to concurrently address individual, task and system factors as aspects which together define the MMI. In our case study, we used an extended applied cognitive task analysis. ACTA was used in previous research to study cognitive tasks to define SA knowledge. Our case study confirmed that ACTA, complemented with additional interrogation on information needs, MMI and information processing, is suitable to study the aspects and to gain insight in MMI.

It was our research hypothesis that the process of information processing and the context of tasks influence the RSA. Our case study clarified how MMI and information needs direct SA assessment. SA assessment modifies the RSA defined by information needs. This approach requires to explicitly define information needs per tasks, which is an extra step compared to current theories. Defining information needs per tasks is a time consuming exercise, requiring a deep understanding of operator goals and tasks. Researchers need input from subject-matter experts to develop a meaningful overview of information needs. Our case study however showed that this extra effort is necessary to gain through understanding of SA in complex MMI context.

Existing theories focus on how to study and define SA knowledge. The analysis scheme emphasizes the relation between SA knowledge, SA assessment and RSA. It helps researchers to define task and context specific RSA. Only if RSA is well defined, researchers are able to decide whether there is a difference between RSA and SA knowledge. Without this insight, it is impossible to conclude whether operators have a lack of situation awareness.

The case study showed that the presented analysis scheme is useful and valid when studying the context of nautical operational network management tasks. With a focus on MMI and information needs, this scheme is especially relevant in complex MMI context. As the theories used to develop this analysis scheme are valid in a broad range of command and control tasks, including aviation and process control, it is expected that the analysis scheme will prove to be useful in these analogue contexts as well.

7. CONCLUSION

This paper presented the results from a literature study on situation awareness (SA) theories. It showed current theories are useful to describe the operator’s SA knowledge and to understand the process of SA assessment. But they are not suitable to clearly define the required situation awareness (RSA), especially in complex man-machine interaction (MMI) contexts. With current theories it remains difficult to recognize and resolve deficiencies of MMI. This paper shows that it is the combination of task, individual and system factors, resulting in the man-machine interaction, which, together with the information needs, directs SA assessment and as such influences the RSA and SA knowledge. Application of the
resulting analysis scheme in practice shows the scheme helped to define RSA together with operators and subject-matter experts. The resulting definition was useful in preparation of observational research conducted to study deficiencies of MMI in SA support. Whether the resulting definition of RSA is the most applicable definition in practice was not part of this research evaluation.

To overcome the limitations of current theories and methods to study SA, this paper discussed the importance of insight in information needs and man-machine interactions. It proposed an analysis scheme as a structured approach to study SA in environments in which operators interact with information systems. The case study showed it helps to gain insight in operator’s RSA. As an advantage over current methods, it helps to better understand the difference between the required situation awareness and the required information needs. Defining information needs per tasks is a time consuming task, but is necessary to understand RSA. The proposed analysis scheme offers a structured approach for a meaningful study of RSA in complex MMI context, but is less suitable for gaining a quick first insight in SA.

Although the analysis scheme proved to be useful in the case study, further application of the scheme in research practice may help to develop more insights in its advantages and limitations. In a follow-up research, we will investigate whether the insights in required situation awareness gained, corresponds to the observable reality. Our future research will aim to recognize MMI deficiencies. To resolve these deficiencies, we will focus on developing interface solutions for an awareness-enhancing informing.

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