How Vessel Traffic Service operators cope with complexity – only human performance absorbs human performance

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The Vessel Traffic Services is a control system in the maritime traffic system where the VTS operators need to cope with a complex environment to contribute to safe and efficient ship movements. By using cognitive task analysis (CTA), the study has explored how the VTS operators cope with complexity. The study shows how complexity requires the operators to have a large variety in their responses, and these responses are based on personal experience, organisational knowledge, teamwork and communication. However, the combination of the operators' experience and complexity in the environment lead to a large variation in the operators' response.

Keywords: maritime traffic systems; complexity; requisite variety; adapting behaviour, cognitive task analysis; vessel traffic services;

Relevance to human factors / ergonomics theory

The VTS operators are important for regulating the maritime traffic system. The complexity in the system requires expert knowledge to know how and when to respond. The paper uses a combination of two CTA-methods to identify the complexity and to learn how the operators cope with such complexity. Further, the paper aims to describe variation in response between operators and explain the reason for variation in the response.

Introduction

The technology revolution in the maritime industry has led to an increased use of computerised control and automation. Over the last decades we have experienced more integration of technology and incremental introduction of highly automated systems, and we expect a future with a continued development of digitalisation, and increased connectivity between ship and shore is expected to follow (DNV GL 2019). In order to prepare for this, the International Maritime Organisation (IMO) introduced an e-navigation strategy to address the harmonised collection, integration, exchange, presentation, and analysis of marine information on board and ashore (IMO 2019). A corollary of technology development in general, and the e-navigation process more specifically, is more and better information available both on board and ashore, and this could cause a change in *how* to conduct safe and efficient navigation in the future Maritime Traffic System (MTS). In the MTS, the on-board crew are *responsible* for safe navigation (van Westrenen and Praetorius 2014), while the task for the shore based Vessel Traffic Services (VTS) is to *aid* the mariner in the safe and efficient use of the waterways (IALA 2016).

The VTS is a young actor in the overall maritime system. VTS is a response to the demands from modern shipping. Larger and less manoeuvrable vessels, higher traffic congestion, and hazardous cargo requires measures to reduce risk. Today there are more than 500 VTS covering both coastal waters and inland waters (IALA 2016). The VTS is a global concept, but a nationally regulated service, hence, we find various setups and roles for VTS around the world. In general, the VTS assists vessels by providing three different services; Traffic Organising Service (TOS) to separate traffic in time, space and/or distance when needed due to safety, Information Service (INS) to maintain a traffic image for the vessels in their area, and Navigational Assistance Service (NAS) to provide navigational information in difficult navigational or meteorological circumstances (IALA 2016).

IMO defines that a 'Competent Authority' should be responsible for the safety and efficiency of vessel traffic (IMO 1997). In Norway, the Norwegian Coastal Administration (NCA) is responsible as the 'Competent Authority' for the VTS. Norway has established five VTS, four of them responsible for areas in territorial waters and one in international waters. All of the Norwegian VTS are manned 24/7 with two operators. The traffic in these areas is regulated by Regulations for Vessel Traffic Services (Ministry of Transportation 2015).

In this study, we have chosen the Norwegian VTS with the highest traffic volume, Kvitsøy VTS. We initially present the setup of the Kvitsøy VTS, subsequently, an incident where the VTS played a significant role to prevent serious consequences.

The setup of Kvitsøy VTS

Kvitsøy VTS has three workstations, where two are continuously manned. The continuously manned workstations are set up as shown in Figure 1. One of the VTS operators act as shift leader, and this role rotates between operators from shift to shift. The main part of the workstation is the *C-Scope* with radar- and AIS-information. The C-scope includes several functionalities such as alarms, visualising procedures, weather and vessel information. The *CCTV* is placed in the top row, and the operator can remotely operate several cameras in the

VTS area. The printed *operational procedures* are placed in flip folders on the top left side of the station. The *SafeSeaNet (SSN*) station provides information of vessels and pilotage. The *Operator Support Station (OSS)* supplies more detailed information of vessels and will have more functionalities such as an operations log in the next upgrade. A *PC* with e-mail and internet access is used for communication externally and internally, and to check publicly available information. The *communication equipment* is used for VHF communication with vessels on the VTS-frequency and on the emergency frequency.

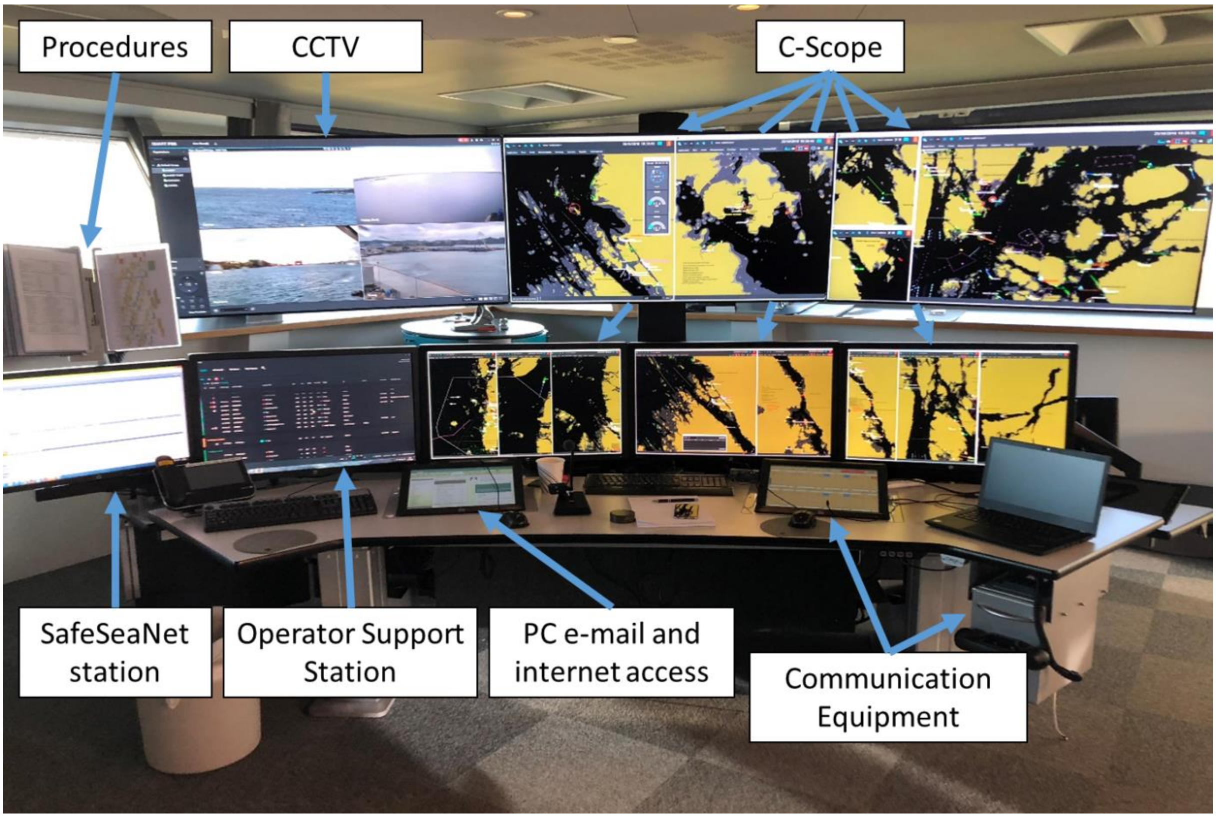


Figure 1: The VTS operator workstation

The incident with MV Tide Carrier

A February morning in 2017 the VTS operators at Kvitsøy were alerted by an anchoring watch alarm for the vessel MV Tide Carrier (NCA 2017). The alarm indicated the vessel was drifting from its anchoring position southwest of Stavanger. After more than ten years out of operational service, the vessel had headed for sea two days earlier. She anchored up awaiting documentation needed for the voyage but started to drift. The weather was rough; a strong gale from the west threatened to ground the vessel on the coast outside Stavanger within an hour if the vessel continued to drift. The VTS operator immediately alerted the vessel and instructed the crew to start the engines and ordered a tugboat to set course toward MV Tide Carrier. The crew on MV Tide Carrier ensured that the engines were running, and the situation was under control. However, based on the communication, the radar information and his ‘gut feeling’, the VTS operator did not trust this information to be correct and initiated an internal alarm. An additional VTS operator was called in to assist the two already on duty. In the following communication, the crew on MV Tide Carrier again told the VTS operator that the situation was under control and the tugboat crew asked the VTS operator if they should return to base. The VTS operator instructed the tugboat to continue towards MV Tide Carrier and ordered a second tug to proceed to the area. The three VTS operators cooperated to handle both this situation and the other traffic in the area. The VTS operator again warned the crew on MV Tide Carrier that they were close to shore, but the crew responded that the situation was under control and the engines were running. Less than ten minutes later, the crew on MV Tide Carrier reported the engines had stopped. The VTS operator ordered the crew to prepare for receiving assistance and coordinated with the tugboats to assist MV Tide Carrier.

A challenging rescue operation followed, but the tugboats were able to rescue the vessel and tow her to sea despite strong winds, high waves, shallow waters and being close to skerries. The VTS operators coordinated resources and cooperated with on-scene coordinators until the vessel was safe alongside port on the afternoon the day after, 30 hours after the anchoring watch alarm was triggered at the VTS.

Figure 2: MV Tide Carrier rescued by a tugboat close to shore (Photo: Norwegian Coastal Administration)

The MV Tide Carrier incident is one example of the VTS playing a significant role in reducing the consequences of an abnormal situation. It exemplifies the complexity in the interaction with the external environment for the VTS operator and shows how operators use expert judgement and experience to interpret the situation and make timely and correct decisions.

Objectives

In our study, we focus on the VTS as a sociotechnical system, described by Praetorius (2014) to be a *control system* in the MTS with interactions internally in the VTS and externally with vessels. The study has two objectives. The first is to identify how the VTS operators use their expert knowledge and strategies in their interactions with vessels. The second is to examine if there is variation in the interaction with the vessels between different operators. The study will be used as an input to discuss the future VTS in a joint project between academia and industry. In the larger project, a human-centred design (HCD) approach will be utilised and the present study presents the initial HCD-step: to *understand and specify the context of use*.

Conceptual framework

The conceptual framework for the analysis is sociotechnical systems theory. Sociotechnical theory are referring to the joint optimisation between social and technical factors (Walker et al. 2008). The sociotechnical systems term origins from the Tavistock Institute research program in the 1950' where separate approaches to either social or technical system was not seen as sufficient (Trist 1981). Trist (1981) points to two aspects of systems theory important for the sociotechnical concept: the interdependency in the system and the connection to open systems. Both aspects are influenced by von Bertalanffy's paper on 'Open systems in Physics and Biology' (1950). The interdependencies where the components are linked to create a unitary whole is a central principle recognised from general system theory. Additionally, similar to systems theory, the sociotechnical system focuses on the relationship between components. The substantive factors are the social and technical system components and the outcome is economic performance and job satisfaction (Trist 1981).

In the VTS, as in many other complex sociotechnical systems, humans are important regulators to maintain system stability. In our case, the humans are important to achieve the individual goal for the VTS as a system, and in addition, contribute to regulation of the maritime traffic system.

The VTS in a systems perspective

One of the main concerns of general systems theory is to understand general relationships in a human-made world through a systematic framework. The challenge of communication between various disciplines is one of the main drivers for the theory (L. von Bertalanffy 1951). A clear and unambiguous language is critical for system design (Long and Scott 2011), and for this paper, the initial step is to clarify what is included in the term system.

Ackoff (1971, 662) defines a system as *a set of interrelated elements*. The VTS is a system linked to other systems, and part of a larger whole. In this paper, we define the vessels operating in the VTS-area as separate systems. Further, we define all systems operating in the VTS-area as a Maritime Traffic System (MTS) and the MTS as a *system of systems* (SoS) as visualised in Figure 3.

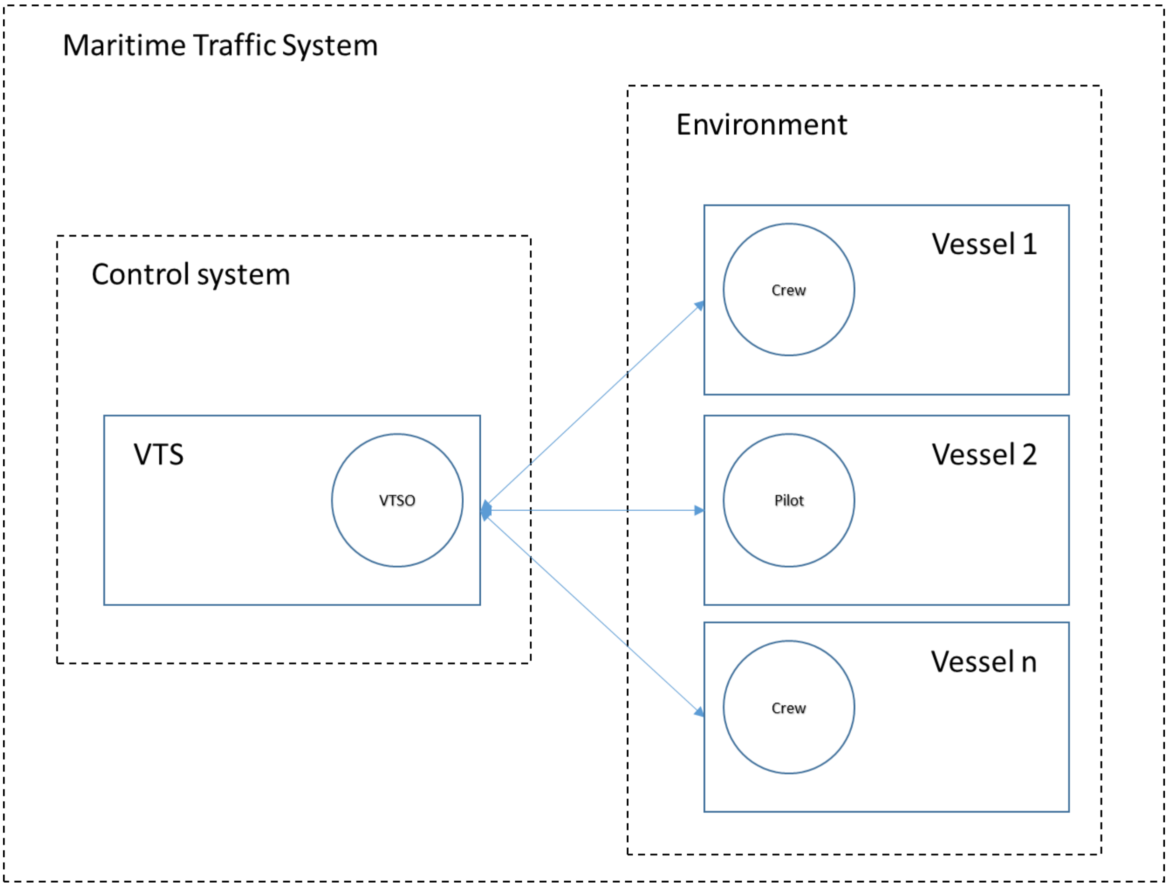


Figure 3: The Maritime Traffic System (MTS) described as a system of systems composed of the vessels in the area constituting the environment and the VTS as the control system

The VTS is an *open system* that interacts with its environment. In open systems, system components adjust to changes by a dynamic interaction with the environment (Blanchard and Fabrycky 2013). Further, Blanchard and Fabrycky (2013) defined a system as being composed of components, attributes, and relationships. In our paper, we consider the VTS operator a system *component*, and we study how they adapt *attributes* (behaviour) in the *relationship* with the environment.

Complex systems, requisite variety and the human role

The term complex or complexity is frequently used to describe the VTS as a system (Nuutinen, Savioja and Sonninen 2007; Praetorius and Hollnagel 2014), the tasks for the VTS (IALA 2016; Praetorius et al. 2012; Praetorius, Hollnagel and Dahlman 2015; IMO 1997) and the MTS as a system (Mansson, Lutzhoft, and Brooks 2017). Hollnagel (2012) states that complexity is widely used, but difficult to define, which is also acknowledged by Flach (2012). While Hollnagel (2012) states that complexity arises when it is difficult or impossible to make predictions, Flach (2012) focuses on the attributes of the problem where an increasing number of possibilities increases complexity. Even if Flach states that complexity should not be correlated with difficulty, both Hollnagel and Flach seem to have a similar perspective: when prediction is challenging, complexity increases.

The VTS is an open system, and even if the responsibility of navigation rests with the individual vessel, the VTS is a control system, and its purpose is to increase safety in the entire Maritime Traffic System. The complexity for the VTS is closely related to the shifting demands of the environment; and the attributes of the VTS needs to change based on these changes. Ashby (1956) coined the concept of *requisite variety,* and explains that only variety in regulations can force down the variety due to disturbance – hence variety can destroy variety. This concept could be used to explain the dynamics between the VTS and the environment. The VTS as a control system (or regulator) needs to have a variety of response that is equal or larger than the variation in the environment. Hollnagel and Woods (2005) suggest that requisite variety should be interpreted to mean isomorphic performance based on functional adequacy rather than on structural similarity. For our study, this means that the VTS as a system needs the requisite variety through functional adequacy created and demanded by the vessels in their area. In addition, Hollnagel (2012) argues that systems have become so complex that tools, procedures and performance need to be adapted to the situation. He further states that performance variability of the operator is normal and necessary.

This implies that we will find variety in the VTS as a system, and in addition we will find individual operator performance variability. Since humans are important regulators to maintain system stability, performance variability is a significant source for creating the requisite variety for the system. However, there is a possibility that operator performance variability could lead to different operational practices, which would be challenging for other systems in the MTS and cause unnecessary variety. The study will highlight both how the operators cope with complexity, but also discuss existing variations between operators and elaborate on the reasons for such variation.

Materials and methods

Hollnagel and Woods (2005) say that all human performance is constrained by the conditions under which it takes place. An important aspect of the context – the conditions for VTS operators – is that they are part of a complex sociotechnical system that interacts with other systems in an overall maritime system-of-systems. Flach (2012) points out that one of the major lessons in cognitive science the last 20 years is context matters. Therefore, we focus on the activity of the operators and the environment in which they work. We use a qualitative approach and an ethnographically inspired perspective on the activity under study. This allows for a richer data set and deeper understanding of this maritime system, but does not support quantification of results. In order to structure the data collection and the data analysis a CTA was chosen.

A CTA is useful for understanding tasks and the outcomes people are trying to achieve. It explores how people think, what they know, what they try to understand and how information is organised and structured (Crandall, Klein, and Hoffman 2006). May and Barnard (2004, 291) define cognitive task analysis (CTA) “as techniques to seek to model the mental activity of a task operator”. Using more than one method or tool in a CTA provides greater leverage and deeper insight (Crandall, Klein, and Hoffman 2006). For this reason, an Applied Cognitive Task Analysis (ACTA) and a Critical Decision Method (CDM) are employed in the study. ACTA is normally used to analyse cognitive demands in a task or scenario, while CDM focuses on non-routine incidents (Stanton et al. 2013). Because our study aims to understand how VTS operators respond to various demands in the environment in everyday operations and abnormal events, CDM was combined with ACTA to identify a fuller range of factors affecting the decision-making of a VTS operator. A combination of observation and interviews was used to collect data while the operators were on duty. Such combination of observation with other data collection is recommended by Crandall et al. (2006) to prevent a misleading and cognitively shallow account.

Sampling

Kvitsøy is the VTS with highest traffic volume in Norway, and in cooperation with NCA this VTS was chosen since it was assumed to give the richest data set. Kvitsøy VTS is continuously staffed with two VTS operators and a pilot distribution unit with 1-3 operators. VTS operators on day and night shifts over three days were interviewed. None of the employees at the pilot distribution unit were interviewed. All VTS operators at work were interviewed, and due to a shift rotation in the middle of the observation period, 7 of 14 of the operators employed on the site were interviewed. The age ranged from 29 to 60 years (mean = 42.4 years, σ=11.8 years), the nautical experience from 2.5 years to 30 years (mean = 14.0 years, σ = 10.2 years) and VTS experience from 6 weeks to 13 years (mean = 5.3 years, σ = 5.5 years). All the interviewed operators were male.

As only the VTS operators were targeted, and the operators at the pilot distribution unit were excluded, the sampling is *purposive*. No random selection was performed regarding VTS experience, nautical experience, age, or gender. Hence, the selection does not fulfil the criteria of being probabilistic, and the sampling is therefore *non-probabilistic*.

Combining Applied Cognitive Task Analysis and Critical Decision Method

ACTA offers a toolkit of interview methods to analyse cognitive demands and was initially used in the firefighting domain (Crandall, Klein, and Hoffman 2006). Militello and Hutton present the method as a streamlined cognitive task analysis tool for use by professionals not trained in cognitive psychology, and their objective is to transition CTA techniques from the research community to the operational community. ACTA aims to elicit critical cognitive elements from Subject Matter Experts (SME) and comprises of a task diagram interview, a knowledge audit interview, a simulation interview and a cognitive demands table (Militello and Hutton 1998).

The Critical Decision Method (CDM) originates from Flanagan's (1954) Critical Incident Technique (CIT) which uses structured interviews for critical aviation incidents. The technique has been used and adapted for various experts to recall previously encountered cases (Hoffman, Crandall, and Shadbolt 1998). Based on an adaptation of the CIT, Klein, Calderwood and MacGregor (1989) developed CDM to model tasks in naturalistic environments to elicit domain knowledge from experienced personnel. The original probes used by Klein et. al (1989) were revised by O'Hare, Wiggins, Williams, & Wong (1998) to include additional information on perceptual and cognitive structures and processes, and provide more detailed probe questions. These revised probes have been rephrased in this study to the future tense to encourage participants to be open-minded about future scenarios and not linking their assessment only to personal experience. An example is one of the probes for cue identification where the original probe is "*how did you know that you needed to make the decision*" which is rephrased to "*how do you know you need to make a decision*".

The work situation for the VTS operators varies between high workload with many interactions with vessels, to quiet periods with little or no interaction. Therefore, a combination of observations and interviews of VTS operators was chosen as the preferred data collection method, since many interactions leads to interesting observations, while the quiet periods allow time for reflections about the situations. Furthermore, reflecting on specific events is a starting point for discussing how situations could potentially develop.

Procedure

The aim was to conduct a cognitive task analysis of *VTS operator tasks when assisting vessels in all phases of the voyage in the VTS-area, from entering area to port*. Previous studies on VTS (Nuutinen, Savioja, and Sonninen 2007; Lützhöft, Dahlman, and Prison 2008; Brodje et al. 2013; Praetorius et al. 2012; van Westrenen and Praetorius 2014; Praetorius 2014; Mansson, Lutzhoft, and Brooks 2017) provided an initial understanding of the context the operators are working in. In addition, a meeting with the NCA was held to learn more about the organisational framework for the operators. NCA made all VTS procedures available for the study, and they were reviewed before the site visit.

To develop a question set based on both ACTA and CDM probes, the knowledge categories from ACTA were merged with the CDM decision-making categories. Probes from both methods were used, and the questions were adapted to a VTS context and translated to the Norwegian language. To get a reasonable amount of questions, overlapping questions were merged. The result was 29 questions, excluding demographic questions. During the site visit, all interviewees were asked the same questions, but different follow-up questions were used based on the discussed event. As different situations occurred, the questions were not always asked in the same order, however all questions were asked during the observations.

The data collection took place at Kvitsøy VTS October 23-25th 2018. In total 38 hours of observations were conducted by one observer. In Table 1 we provide an overview of the time periods of observation, which operator primarily being observed, which shift the operator is on, and the main event during the observation period.

Date	Time	Observed operator	Shift	Main event
23/10	11-14		Day	Familiarisation
	14-17	A	Night	Question set
	18-22	B	Day	Question set
	22-01	C	Night	Question set
24/10	08-12	D	Day	Question set
	12-14	B,D	Day	Replay and discusisons from incidents
	14-15	C	Night	Review and discussion of experience reports
	16-18	A	Night	Review and discussion of experience reports
	18-20	E	Day	Question set

	20-22	F	Day	Question set
	22-01	G	Night	Question set
25/10	01-03	G,C	Night	Replay and discusisons from incidents
	09-11	E	Day	Question set
	11-14	F	Day	Question set
	14-16	G,C	Night	Discussion of on-going NCA initiatives

Table 1: The table provides an overview of the period of observation, which operator primarily being observed, and the main event for the observation period.

In the study, we applied the basic and optional probes from the ACTA and CDM-method for the knowledge categories characterising expertise. The interviews captured both individual tasks and combination of tasks where expertise knowledge is important for the outcome. To determine difficult cognitive elements, the probes were used to reflect on both about on-going operations and on previous experiences. The responses were documented and marked with the question number. The interviewer merged the data from all the interviews shortly after the interview.

Analysis

Militello and Hutton (1998) propose to analyse results in a *cognitive demands table*, and presented suggested headings for such a table. They recommend that practitioners of ACTA-studies adapt these to focus on the relevant information in different projects. In our study, we used the headings: *Knowledge categories, difficult cognitive elements, environmental variables, and cues and strategies*.

The cognitive demands table was used to gain an overview of how operators cope (cues and strategies used) in different contexts (environmental variables). The initial plan was to describe how VTS operators cope with complexity, by discussing the identified cues and strategies in combination with environmental variables. However, to include all field data in one table was difficult and, furthermore, there was data overlap between the different knowledge categories. It was decided to use fewer categories and perform a more detailed discussion of the results. The data was therefore initially coded manually and inductively, resulting in the following parent nodes: the use of operator experience and knowledge ("*operator*"), cooperation with other team members ("*teamwork*"), the use of procedures, equipment or established routines ("*organisational knowledge*"), and how communication was used to interpret or affect the situation ("*communication*"). The data was then imported to the qualitative data analysis software NVivo and deductively coded on these categories to verify that all relevant data was discussed.

Each parent node consists of 2-4 child nodes, and in the results, we present the number of VTS-operators that responded on matters related to each child note. However, it is important to underline that in this study we asked questions related to the *situation* the operator experienced during the observation. Consequently, responses from operators are linked to different situations. Hence, quantification is a useful indication of the importance of the child node but needs to be understood in the context the responses were given. Consequently, in the results we describe the variation of responses for each child node. However, at this subordinate level, we do not present any quantification. During the observation, the participants sometimes elaborated on how *other* operators could respond to the same situation. In the results, we describe these findings as '*some* operators' versus '*other* operators'. Additionally, in occasions of two operators discussing the same situation, i.e. the same context, the results are presented clearly as two different perspectives or responses.

Reliability and validity

Credibility is to establish isomorphism between the respondents views and the researchers reconstructions (Fishman 1999). One weakness of the study is not filtering out less experienced VTS operators; the data will thus include both variables that make it difficult for the operator *and* what creates uncertainty. The strength of the study is that it covers all three areas Militello and Hutton (1998) use to prove validity of the ACTA method. First, the study addresses cognitive issues by using probes from both CDM and ACTA. Second, the study gathers experienced based knowledge by combining interviews and observations at the VTS. Third, the information gathered can be used as important information for novices to learn about the actual situation for a VTS operator.

Klein and Armstrong (2004) raise a concern with reliability of data collected in CDM due to respondents' memory degradation. The possible impact on the present study is reduced since all CDM-related questions are rewritten to future tense, but not eliminated since the responses will be linked to the participant's experience. The reliability of the study could be affected by focusing on the situation occurring during the site visit, while other situations are left out. On the other hand, the reliability is improved by using the same questions with all operators, and information repeated by more operators is given more weight in the data analysis.

Results and discussion

In the results and discussion section we discuss how the operators cope with complexity based on the parent nodes:

- operator experience,
- teamwork,
- organisational knowledge,
- communication

We present child nodes to each of the parent nodes, where each child node is quantified by indicating how many out of the seven operators who had responses linked to the child node. We underpin each child node by a more detailed representation of the responses linked to the node, including examples from the observation. At the end of the discussion of each parent node, we present the variation of operator responses linked to the node.

Operator experience

The VTS operators' experience, such as their background and years of service, is a major source for coping with complexity. The experience affects how the VTS operator gathers and interprets information from the environment. The results show two major components; nautical experience and experience as VTS operator.

Six operators highlighted different aspects related to the nautical experience during the observation. Operational experience, ship type, rank, and years of experience, are used to imagine the situation on the bridge and what information and/or type of service the crew needs. One operator expresses this as using the experience to imagine what *'would be nice to know if it was me on the bridge of that vessel'*. The operators also use the operational experience to assess how various external factors such as weather and traffic affect the vessels. This is stated from one operator as '*building a mental maritime picture'* and using this to picture when the visibility is so poor that he increases the distance between vessels. Further, the operators point to variation in type of vessels and experience from different trades between the operators is a factor that has an influence on operator response. They explain that VTS operators with nautical experience from a large vessel will interpret a situation differently than operators with experience from smaller and faster vessels. Furthermore, they claim experience as rank of captain and years of experience is useful in situations where they must be more authoritarian.

All seven operators point to VTS experience is the basis for understanding the traffic picture in the area. Experienced operators have extensive knowledge of the vessels normally trafficking the area, including their operational patterns, capabilities, and limitations. The development of traffic and vessel capabilities, local knowledge of weather and familiarity with regulations are applied, affect the type of service and information provided. Operators emphasize that with more experience they spot situations earlier and learn when to provide information. One operator explains this as *'becoming more experienced, I provide information at the 'right time', when I had less experience, the information was given too late or too early*'.

Two operators said they often have a 'gut-feeling' about which vessel they need to pay special attention to. The reason for this gut-feeling was said to be a holistic assessment of vessels not behaving as expected. This could be triggered by the individual operator's knowledge about a ship type (nautical), or it could be triggered by a vessel not following a known traffic pattern (VTS-experience). However, the operators say that it often could be a combination of both types of experience that initiated increased awareness from the operator.

The results show that different experience creates a variation in which VTS service they provide. As an example, the operators' use of the message marker 'instruction', which is the strongest and most directive communication to a vessel, is used differently. While one of the most experienced operators says he has used this word once or twice in his entire career at the VTS, another operator with less experience says he uses it every day. Another example is the effort the operators' make to get in contact with vessels entering the VTS area. Some operators say they start to call the vessel at both the VTS-frequency and at channel 16 (distress channel) when the vessel approaching the VTS-area. They say that other operators wait for the vessel to initiate radio contact, and rarely use the distress channel to call the vessel. The variation in response to situations indicates the operators interpret the situation differently, and the reason for this could be various backgrounds. The nautical experience has a potential to have a large variation due to operational experience, ship type, rank, years of experience, and where and which trade they have been a part of. VTS experience seems to have less variation, and the main variable is the years of experience.

Experience is imperative for how the operators cope. They use this to interpret the situation and to choose response, and it is shown that variations in nautical and VTS-experience create variations in the operators' response in which and when services are initiated.

Teamwork

The VTS operators work in a shift setup of two operators, but responsible for two different geographical areas. In short periods, one operator can take over the responsibility for both areas. Even though the operators have separate areas of responsibility, *cooperation between the operators* on duty is important. A different aspect to cope, is the possibility to *call for an extra operator* in challenging situation.

Five operators highlight different aspects of cooperation between operators as significant in their everyday operations. A shift rotation on the VTS lead to different VTS operators teamed up from week to week. The VTS procedures make sure that VTS operators with little experience are always teamed with someone with more experience. The operators are positive to this rotation, and feel it standardises the way they are operating. One operator concisely refers to this as *'we are learning tricks from each other'*. The VTS operators believe this make it possible to learn from different operator's perspectives since all have different areas of expertise, experience, and area of interest. Some is said to be more interested in technical improvements, while others are more involved in concept development. It was observed that the operators often discussed solutions with their colleague, and several examples of operators seek advice prior to decision and discussion of solutions after decision has been made, was seen. This discussion seemed to be open, and equally often being the experienced operator approaching the less experienced as the other way around. No operational personnel, except from the shift on duty, are working within normal working hours every day and could be a media for experience exchange between the shifts. This is said to be a barrier for experience exchange, and if someone with technical interest are off duty for some weeks, improvements in this area will be on hold.

In a crisis, the VTS operators have the possibility to call for an extra operator, as minimum one of the two operators on the resting shift must be on the VTS station. Three operators point to that calling for an extra operator is important. The VTS operators shared stories of several occasions where operators were called in to help the two on duty. One operator gives an example of an incident and stated that *'this incident would never be possible to handle without the extra operator'*. A typical example was assisting a vessel in distress in combination with heavy traffic on the same radio frequency. In such circumstances, the VTS operator allocates a separate channel for the vessel needing assistance, and a third operator take over the 'normal' traffic. The VTS operators emphasize that they are dynamic in their set-up and they discuss continuously how to handle the situation and how they can share the workload in the best possible way. In the middle of the operations room the operators have a large screen and it was observed that this was used to present information about vessel type and weather forecast that can be important for the team.

Teamwork is said to be essential for the operators. They discuss solutions and call for an extra operator if needed. There was no or little variation in the response from operators about the importance of cooperation with colleagues.

Organisational knowledge

The term organisational knowledge is used to describe how the organisation tailor the *procedures*, *equipment*, and *regulation* for the situations the operators experience. The Ministry of Transportation has delegated the authority for the regulation of vessel traffic services to the Norwegian Coastal Administration (NCA). This delegation also includes measures for vessels in distress (§38) in regulation of fairways. In practical terms, the NCA is responsible for providing VTS services in the area, and measures such as ordering vessels to take tug on VTS discretion. The NCA has established a traffic separation system in the area, including a roundabout, restricted part of the fairways for large vessels, restricted passage of large vessels in some areas, and limited the use of parts of the fairways in reduced visibility.

Procedures

To govern the work practice of the VTS, NCA issues operational and administrative procedures. The NCA HQ issues general procedures to all of their VTS', and the individual VTS is responsible for tailoring the procedures for local use. The review of the procedures shows that most of the operational procedures are prescriptive. Prescriptive procedures describe broadly the area of responsibility of the VTS operator, while descriptive procedures define more in detail the criteria for *when* to act, and in addition stating *how* to do their task. An example of a prescriptive phrase found in the VTS procedures is "*when the VTS operator assess that it is a risk for collision, the operator should warn the vessels"* (our translation). In such procedure, it is up to the expert judgement of the VTS operator to assess if there is a risk for collision. An example of a descriptive procedure is *"when a forecast of wind stronger than 18 m/s (force 8) is issued the operator shall recommend the vessel to be ready for immediate start*" (our translation). The descriptive procedure is more detailed of when to act and which action to take.

The seven operators are concurrent on stating that making descriptive procedures for *all* situations is not possible nor expedient. The operators argue it is too many different situations for descriptive procedures being useful, and prescriptive procedures are the right choice. However, the VTS operators are positive about descriptive procedures, as they descriptive procedures is easy to follow since criteria is well defined. One example was observed; the weather deteriorated and the procedure for anchoring was used. This procedure is descriptive and described actions to take based on wind strength and vessel size. The VTS operator refers to the criteria in the procedure when asked about the reason for taking action in the situation and he explained that the detailed procedure is helpful to decide which action to take and when to initiate it. The VTS has implemented a function on the map on their system 'C-scope' so the procedures for the geographical area could be brought up on the screen. In general, the descriptive procedures are made available on the screen, which is natural since these are often linked to geographical areas, while the prescriptive procedures are more scenario specific. Even if the procedures were available, they are not often brought forward on the screen, and the operators say the reason is that the criteria are well known. This was confirmed when the wind increased, and one operator initiated the procedure for warning vessels at anchor without needing to look it up. Additionally, all procedures are available on printouts on the workstations but were not used during the observation period.

The procedure where the VTS is delegated the authority to order vessels to take assistance from a tug were mentioned of four of the VTS operators as especially important. The VTS is never held responsible for any costs for such decision. The operators highlight the importance of such delegated authority, and operators have many examples of situations where tugs have been ordered. The operators' impression is that many captains are relieved when the VTS order them to use tug, since the shipping company restricts the crew to take actions that lead to extra cost. It seems like the use of tugs is one of the important safety measures for the VTS operator when a situation creates a concern.

The observation shows that the operators are well aware of the procedures, even though they are not directly in use during operations. Some descriptive procedures have been developed, and the operator knows the criteria, and they are also available on C-scope if needed. The delegated authority of ordering assistance of tug is an important safety measure for the VTS operators. Prescriptive procedures create a basis of what the VTS operators should do, but not how the VTS operators should respond. The study shows that the operators feel that the variation in situations does not allow for replacing the prescriptive procedures with descriptive procedures. One consequence is that the procedures to a substantial extent allow for a large variation in operator response.

Equipment

All seven operators discuss various aspects of the workstation during the observation. The operators reflect on both that functionality of the workstation affects how well VTS-operator is supported, and issues with the workstation they need to pay special attention to. Four of the operators elaborate on both how they are supported by functionalities, and on issues that is challenging with the workstation. Two operators mention only issues that is challenging about the workstation, while one operator highlights only the positive contribution of functionalities.

The operators say the system is under constant improvement. Examples of functionalities already implemented and helpful for the operators are the triggering of alerts if vessels at anchor started to drift. However, to find the right alarm level where false alarms are avoided, is an on-going effort. As shown in the event with MV Tide Carrier, drift alarms provide the operators with time to react. Other functionalities such as tagging of vessels that require special attention with a purple triangle is used both to keep the attention for the operator on watch and could be used in hand-over to increase the awareness. Marking of vessels with towing capabilities is said to be useful in time critical situations to identify vessels able to assist. On the other side, the operators are aware that AIS (Automatic Identification System) is not always reliable, and they correlate this with other sources (such as radar, voice communication or CCTV). One operator expresses that the functionalities might affect the future area of responsibility for the VTS by saying *'with the increased functionality of the workstation it could be possible to monitor a larger geographical area in the future'*. This implies that the functionality of the new workstation reduces the workload for the operator. To cover a larger geographical area could therefore be a possibility but might also be necessary to reduce the risk of fatigue by keeping the VTS operators activated.

Since the functionalities are in constant development and some operators are more interested in technical developments than others, some operators say there are variations in how and when the functionalities are used.

Regulation

Four of the operators reflect on how the regulation of traffic using traffic separation systems, restricting passage in parts of the fairway, and limiting the use of fairways in reduced visibility, affects the situation for the VTS operators.

The operators say the traffic separation systems increases predictability. Further, the operators say that separation systems make it easier for the crew to communicate their intentions, and for the VTS operators to create an efficient traffic flow. During the observation period it was exemplified in a situation where a vessel started to sail close to the separation line between the north and south corridor. The operator informed the vessel and an immediate turn was observed.

Restriction in passage is a different safety measure to avoid vessels to meet in narrow waters. To regulate traffic in accordance to these regulations is one of the most challenging tasks for the VTS operator, and the situation is affected by vessel type (size and manoeuvre speed), weather (current, visibility, and wind) and crew (geographical knowledge, language knowledge, use of dialect and local names). Some operators claim that one of the challenges with the existing regulations is that the crew are not aware of them, and it could be beneficial if the vessels could integrate some more information in the Electronic Chart and Display System (ECDIS) about regulations in the area they sail. The VTS operators use many different sources to create an understanding of the traffic picture to ensure a safe and efficient traffic flow in the regulated areas. In addition to the radar information, the operators use departure information in their Operator Support Station, and CCTV of the area and the ports in the vicinity. If the CCTV shows vessels starting up at one of the ports, the VTS operators call the vessel on VHF to get their intentions. In the study it was observed some variations of when operators called for intentions. However, the situations were not comparable, hence, it could not be concluded the variation is due to operators or due to situation.

It was observed an established unformal regulation where passenger vessels crossing the area were given priority. This was both observed and said to be an established routine for the operators.

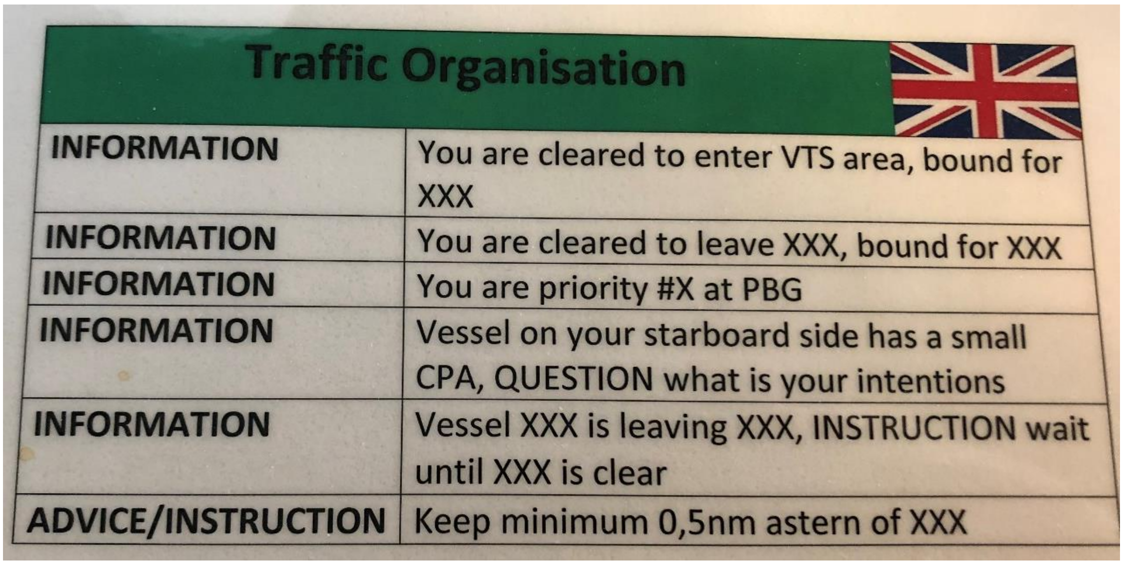
Communication

All vessels subject to regulation (in general vessels of 24+ meters length) must report when entering the VTS-area, or before leaving port within the area. The main communication between VTS and the vessel is done via VHF-radio, primary on the VTS working frequency, and secondary on the international distress frequency (channel 16). During the site visit two calls from vessels to VTS using mobile phone was observed, all other communication was done via VHF-radio. The communication between the VTS and vessel is recorded, and the VTS operators have a playback device for instant playback if any radio calls were missed. The communication between the VTS-operators is in Norwegian language and is direct without use of any communication means such as telephone, this communication was not recorded.

Four of the VTS operators emphasise how they listen for indications of the crew not understanding the communication. These indications can be hesitation, wrong read back, or other ‘logical breaches’. The VTS operators gave several examples of vessels stating they have the situation under control, but the reality turned out to be different. Recording from incidents are logged by the VTS. The VTS operators presented recordings from incidents that indicate that if the VTS operator had acted solely on the information from the vessel, an accident could have occurred.

All seven operators say it is large variations in how the operators communicate with the vessels in the area. The operators say the differences are about using different terms, variation in how much information is given, and how early the information is given. The operators explain the variation by the differences in experience and background. All operators say they become more aware of the communication with the vessel when getting more experience. They listen to the read back from the crew, and the response could indicate how well the crew understands the situation. This is used as a basis to assess which service that is provided, how much information given, and when the information is given.

All seven VTS-operators refer to IMO’s standardised communication when asked if it a standardised way to communicate their decisions, and all operators reflect on the importance of communication being ‘correct’. The IMO’s Standard Marine Communication Phrases (SMCP) was developed by IMO to reduce the problem of language barriers and to avoid misunderstandings (IMO 2001). The SMCP has defined eight message markers: *instruction, advice, warning, information, question, answer, request,* and *intention*. These message markers should be used preceding the message transmitted. The IMO SMCP state that the use of message markers is used on the discretion of either the shore or ship personnel (IMO 2001). However, it is recommended by IALA that message markers are used when VTS communicates with vessel (IALA 2012). The local VTS procedures state that the main rule is to use message markers in their communication. The exception is a routine for not using message markers in communication with the ferries with frequent departures in the area. The VTS operator has all message markers printed, laminated, and available the workstation in both English and Norwegian language. In addition to the message markers, the printout included examples of standard phrases to be used together with the message markers (Figure 4).



Traffic Organisation	
INFORMATION	You are cleared to enter VTS area, bound for XXX
INFORMATION	You are cleared to leave XXX, bound for XXX
INFORMATION	You are priority #X at PBG
INFORMATION	Vessel on your starboard side has a small CPA, QUESTION what is your intentions
INFORMATION	Vessel XXX is leaving XXX, INSTRUCTION wait until XXX is clear
ADVICE/INSTRUCTION	Keep minimum 0,5nm astern of XXX

Figure 4: The message markers were available in both VTS workstations

The use of message markers was observed in some communication with the vessels, and then mainly used when communicating in English. It was not observed that vessels initiated the use of marker words during the site visit. The VTS operators are concurrent saying that message markers are used more frequently now than in the past and they welcome the use of more standardised communication. The operators say they are conscious that they should reduce communication as far as possible to avoid that crew ignoring the communication on the frequency. One operator defines that communication should be '*short, concise and correct'* another operator uses the term *'assertiveness'* to describe how the communication should be.

English as the common language for navigational purposes has been used since an agreement in IMO Maritime Safety Committee in 1973. The Norwegian Vessel Traffic Regulation state that the navigator should be able to communicate in Scandinavian or English language if sailing without pilot (Ministry of Transportation 2015). The internal procedure for the VTS also define communication to be in Scandinavian or English, and in addition, that communication should ensure the involved vessels had a common understanding of the situation. Further, a vessel with English-speaking bridge officers taking pilotage should communicate primarily in English. If a conflict between vessels communicating in different languages occur, the VTS operator needs to repeat important communication on both languages.

The observation shows that Norwegian language is primarily used. Vessels with English speaking officers communicate in English language until the pilot take over communication. The language is then switched to Norwegian. The VTS operators give examples of situations where the use of Norwegian language results in other vessels in the area not understanding the situation, and the VTS operators assess this to be a safety risk. In addition, the use of Norwegian language is problematic for the non-Scandinavian bridge personnel on the vessel under pilotage. The VTS operators say they always respond in the same language as the vessel calling them, and when the pilot calls the VTS in Norwegian, they respond in Norwegian. Some of the VTS operators advocate that all communication should be carried out in English language. They feel that English would reduce communication, make the communication easier and more concise. Other operators point to using English also will reduce risk of misunderstanding due to difficult Norwegian dialect. The VTS operators elaborate on some challenges to be aware of when using English language, one is that English language would be a challenge for some of the local crew operating in the area, and especially the first period after such change could be difficult. Another challenge is when using English language; it is more difficult to use toneme to indicate criticality. The toneme uses different tones for different meanings and could underline the criticality in the situation. One example was used to prove this point and a replay of a critical situation where a vessel was close to run aground at a skerry was avoided by a clear and concise instruction with a directive toneme in Norwegian and the crew responded immediate. A different scenario was observed on the site visit where the operator wanted the vessel to alter the course to get a safer distance to shore and used a softer toneme, since the situation was not critical. This exemplified that even if the words used in the two radio calls were similar, it was a sharper toneme in the first example, leaving no doubt of which scenario that was critical of the two.

Communication is an important contributor for coping by providing information of the situation on the vessel, and obviously to pass information related to the VTS service. When, what and how communication is carried out is affected by the operators' background and situation they experience. The VTS operators are affected by how the pilot and the crew communicate, as they respond in the same language as they are called by. The variation between operators, and difference between the procedure and actual behaviour is conspicuous. Several causal factors for this situation such as language proficiency in the industry, culture, resist of change for standardisation was discussed by the operators, but no single apparent reason was concluded.

Conclusions and further work

In our study, we used a cognitive task analysis to explore how VTS operators use expert knowledge and apply strategies to cope with complexity, and to explain differences between operator responses and possible reasons for the variation in response.

The results show that VTS operators cope with complexity using both *nautical* and *VTS experience*. Their nautical experience is used to understand the situation that the crew and the ship is in – including the actions available to them – and to decide on appropriate actions. Their VTS experience provides an understanding of the traffic picture in the area and allows the operators to spot situations early and provide VTS service at the right time.

The operators also use a number of supporting means and structures to scaffold their work. First and foremost, *teamwork* is essential for coping since the operators can seek advice from their colleagues and call for an extra operator if an abnormal situation occurs. *The organisation* facilitates for coping by providing operator procedures, equipment and traffic regulations. A typical example is the procedure that gives the VTS operators the authority of ordering a tug, which is perceived as an extra safety measure in critical situations. The implementation of traffic separation schemes has been positive for coping since it increases predictability and makes it easier for vessels to communicate intentions. The VTS operators are also supported by the functionalities of their workstation to reduce the response time and increase awareness, such as alerts and tagging of vessels. *Radio communication* in particular is imperative for how the VTS operators' cope with complex situations. The operators listen for indications of the ship crew not understanding the communication, or being uncertain, and such indications affects how the VTS operators respond to a situation. Another aspect of communicating with the vessels is how the operators use different toneme in their messages to indicate criticality, as it is not only important *what* is said, but also *how* it is said.

The analysis has highlighted differences in operator responses and reasons for the variation, and the following sections review the variation in use of the supporting means. Diversity in nautical experience, such as experience with different ship types and rank on board, *and* the length of service as a VTS operator affects *how* the operators provide the VTS service. This comes into play when applying the procedures. For the most part, the procedures are prescriptive – providing an outline of what the operator is responsible for, while a few are descriptive – stating in more detail when and what to do. The use of prescriptive procedures naturally allows for a large variation in operator response. Furthermore, even though the functionalities of the workstation support the operator, the extent of use of these functionalities varies, where one identified reason is the individual interest in technology. How operators initiate communication, what is communicated and how they communicate with vessels differs from operator to operator, which the operators are aware of. In addition, there is a difference between how operators actually communicate and what the procedures prescribe. Some operators communicate according to the procedures, while others rarely use standardised communication phrases. The difference between operators are explained by the differences in nautical experience, and although not conclusive, other factors were mentioned in the interviews as potential reasons, for example language proficiency in the industry, culture, resistance to change for standardisation.

Applying Ashby's law of requisite variety to this domain, the VTS as a regulator of a maritime traffic system must have the same or larger variety as the environment it controls. The VTS operators are the most important system component, as they adjust their attributes (behaviour) to meet the variety in the environment. This study describes how the VTS operators cope with complexity, and further identifies differences between operator responses. As the title of this paper indicates, the performance of the VTS operator absorbs the complexity in the environment. Hence, we adopt, and adapt, Ashby's law of requisite variety and conclude that only variety in human performance (at a VTS) absorbs variety in human performance (on a vessel).

The *generalisability* of the results is influenced by the sample size of respondents, the choice of VTS, and if the data has been correctly interpreted and presented. 50 % of the work force at the VTS was interviewed; the selection is therefore assessed to be representative. The *transferability* of the results may be limited by visiting only one VTS. However, the NCA is responsible for the five VTS in Norway, and centrally govern the procedures and conduct internal audits. By selecting Kvitsøy VTS, due to it managing the highest traffic volume in Norway, we would expect to get a rich data set. In addition, the study provides a 'thick' description by discussing situations in detail and analysing why the operators choose their responses, an approach that supports transferability (Lützhöft, Nyce, and Petersen 2010). This study provides an increased understanding of how VTS operators work in different contexts and in various conditions. Taking into account the abovementioned limitations, we conclude that it is a contribution to the field of VTS studies.

In future work it is suggested to use this knowledge towards an implementation of standardisation. When standardising behaviour, it is tempting to reduce variety. However, this study emphasises the need for understanding the variety demands of the environment before limiting the variety of the regulator system. In the perspective of the VTS, the standardisation process of introducing traffic separation schemes has reduced the variety in the environment of the VTS operator. The result has been increased predictability for the operator and easier communication of intentions for the vessels. A future study should focus on how more or different use of regulations could affect variety in the maritime traffic system.

Further, a future study could explore more in detail the reason for differences in communication in the maritime traffic system and identify which differences could be reduced.

Finally, the study can be used for understanding the context the VTS operators work in, hence being as part of the foundation for development of the future VTS.

Declaration of interest statement

No potential conflict of interest was reported by the authors.

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Figures

Figure 1: The VTS operator workstation

Figure 2: MV Tide Carrier rescued by a tugboat close to shore (Photo: Norwegian Coastal Administration)

Figure 3: The Maritime Traffic System (MTS) described as a system of systems composed of the vessels in the area constituting the environment and the VTS as the control system

Figure 4: The message markers were available in both VTS workstations

Appendix 1 – Knowledge categories and adapted VTS questions

Knowledge categories ACTA and CDM	**Interview question**	**Question nr**
Goal Specification (CDM)	What do you think the vessels are expecting from you in this situation?	5
	Do you always provide the same service in these situations?	9
Cue Identification (CDM)	What features are you looking at when you take your decision?	4
Expectancy (CDM) / Improvising (ACTA)	What are you expecting to happen in this situation?	6
	Do you improvise, or do you have a standardised course of action in such situations?	10
	Do you recognise the situation from previous situations, and if so, how do you use the experience to decide what to do?	7
Conceptual Model (CDM) / Developing and knowing when to apply tricks of the trade (ACTA) / Meta-cognition (ACTA)	Are there any situations in which your decision will be different?	13
Influence of uncertainty (CDM)	What could cause uncertainty of the reliability of relevance of the information available?	16
	What could be difficult for a novice in this situation?	14
Information integration (CDM)	What is the most important piece of information that you need to formulate the decision?	15
Situation awareness (CDM and ACTA) / Diagnosing and predicting (ACTA)	Can you give me an example of what is important about the big picture for this task? What are the major elements you have to know and keep track of?	3
	Do you think you have a better overview of the situation than the other actors (on the vessel)?	19
	To which degree is it possible to plan for what is going to happen on your watch?	1
	How do you know what is going to happen the next 30 minutes?	2
	Is there any additional information you would like to have before formulating the decision?	17
Options (CDM)	Is there any other alternatives available to you other than the decision that you think of?	11
	Why were these alternatives considered inappropriate?	12

Decision blocking- stress (CDM)	What could make the decision-making process difficult to process and integrate the information available?	18
Basis of choice (CDM)	Do you think that you could develop a rule, based on your experience, which could assist another person to make the same decision successfully?	22
	Do you think that anyone else would be able to use this rule successfully? Why/Why not?	23
	Do you think that other operators will take the same decision as you?	24
	Are there any formal (written) procedures to support you in making the decision?	20
	Are there any informal but established way to support your decision?	21
	Are there a standardised way of communicating your decision?	25
	Does the recipient of information affect your decision, or how you communicate your decision?	26
	Do you experience mistrust from the vessel side?	27
Analogy/ generalisation (CDM)	Have you change the course of action when becoming more experienced?	8
Compensating for equipment limitations (ACTA)	Have you experienced a mismatch with your experience and what was presented by the equipment?	28
	Have you experienced that you trust your own experience more than you trust the equipment?	29

Appendix 2 – Interview guide

D1	VTS experience
D2	Nautical experience
D3	Age
D4	Gender
1	To which degree is it possible to plan for what is going to happen on your watch?
2	How do you know what is going to happen the next 30 minutes?
3	Can you give me an example of what is important about the big picture for this task? What are the major elements you have to know and keep track of?
4	What features are you looking at when you take your decision?
5	What do you think the vessels are expecting from you in this situation?
6	What are you expecting to happen in this situation?
7	Do you recognise the situation from previous situations, and if so, how do you use the experience to decide what to do?
8	Have you changed the course of action when becoming more experienced?
9	Do you always provide the same service in these situations?
10	Do you improvise, or do you have a standardised course of action in such situations?

11	Are there any other alternatives available to you other than the decision that you think of?
12	Why were these alternatives considered inappropriate?
13	Are there any situations in which your decision will be different?
14	What could be difficult for a novice in this situation?
15	What is the most important piece of information that you need to formulate the decision?
16	What could cause uncertainty of the reliability of relevance of the information available?
17	Is there any additional information you would like to have before formulating the decision?
18	What could make the decision-making process difficult to process and integrate the information available?
19	Do you think you have a better overview of the situation than the other actors (on the vessel)?
20	Are there any formal (written) procedures to support you in making the decision?
21	Are there any informal but established way to support your decision?
22	Do you think that you could develop a rule, based on your experience, which could assist another person to make the same decision successfully?
23	Do you think that anyone else would be able to use this rule successfully? Why/Why not?
24	Do you think that other operators will take the same decision as you?
25	Are there a standardised way of communicating your decision?
26	Does the recipient of information affect your decision, or how you communicate your decision?
27	Do you experience mistrust from the vessel side?
28	Have you experienced a mismatch with your experience and what was presented by the equipment?
29	Have you experienced that you trust your own experience more than you trust the equipment?

Data

The data that support the findings of this study are available on request from the corresponding author, TR. The data are not publicly available due to containing information that could compromise the privacy of research participants.