



Special section paper

Distributed situation awareness in complex collaborative systems: A field study of bridge operations on platform supply vessels

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This study provides empirical data about shipboard practices in bridge operations on board a selection of platform supply vessels (PSVs). Using the theoretical concept of distributed situation awareness, the study examines how situation awareness (SA)-related information is distributed and coordinated at the bridge. This study thus favours a systems approach to studying SA, viewing it not as a phenomenon that solely happens in each individual's mind but rather as something that happens between individuals and the tools that they use in a collaborative system. Thus, this study adds to our understanding of SA as a distributed phenomenon. Data were collected in four field studies that lasted between 8 and 14 days on PSVs that operate on the Norwegian continental shelf and UK continental shelf. The study revealed pronounced variations in shipboard practices regarding how the bridge team attended to operational planning, communication procedures, and distracting/interrupting factors during operations. These findings shed new light on how SA might decrease in bridge teams during platform supply operations. The findings from this study emphasize the need to assess and establish shipboard practices that support the bridge teams' SA needs in day-to-day operations.

Practitioner points

- Provides insights into how shipboard practices that are relevant to planning, communication and the occurrence of distracting/interrupting factors are realized in bridge operations.
- Notes possible areas for improvement to enhance distributed SA in bridge operations.

The oil and gas industry is dependent on services from the maritime industry for rig-moving operations, platform supply operations, and standby services, among other functions. Because of the potential for severe damage to human, environmental, and

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economic assets, collisions between attendant vessels¹ and offshore facilities are among the worst-case scenarios in the industry. On 8 June 2009, such an event occurred when the well-stimulation vessel *Big Orange XVIII* lost control and collided with an offshore facility on the Norwegian Continental Shelf at a speed of approximately 9.7 knots. Although the consequences were limited to financial losses, the Norwegian Petroleum Safety Authority considers this incident to have had a large hazard potential (Kvitrud, 2011). In general, collisions between attendant vessels and offshore facilities involve the risk of damage to substructure and hydrocarbon pipelines, with subsequent leakage and possible ignition and fire.² According to the investigators in the *Big Orange XVIII* case, the direct cause of the collision was the duty officer's assumption that the vessel was on manual steering when it was, in fact, on autopilot (Norwegian Petroleum Safety Authority, 2009). As a result, all attempts to steer the vessel manually failed, and the ensuing collision with the offshore facility was unavoidable.

From 2001 to 2010, 26 collisions between attendant vessels and offshore facilities on the Norwegian continental shelf were reported, and at least six are believed to have had catastrophic potential (Kvitrud, 2011). These six cases were analysed in two earlier studies that sought to identify common contributing factors. Oltedal (2012) found that human errors in detecting or interpreting a technical state or error were the direct cause in four of the six cases. These findings are in agreement with the conclusions of Kvitrud (2011), who identified poor understanding of and training in advanced technical equipment as important underlying factors. A recent study of 23 available accident reports from 2001 to 2011 concerning collisions between attendant vessels and offshore installations on the Norwegian continental shelf suggests that 18 of 23 collisions were caused, at least in part, by the bridge teams' loss of situation awareness (SA) (Sandhåland, Oltedal, & Eid, 2015). SA was then defined as 'awareness of what is happening around you and understanding what that information means to you now and in the future' (Endsley, 2012, p. 13). Another notable finding of the Sandhåland *et al.*'s (2015) study was that planning failure was an antecedent to loss of SA in 10 of these 18 cases. A typical example of planning failure was inadequate use of available checklists prior to the operation, which in turn caused a lack of awareness regarding the vessels' technical status. The study also identified communication failure as an antecedent to loss of SA in seven of the 18 cases. An example of a communication failure is the inadequate transfer of command at the bridge or the failure to transfer critical information during shift handover. Finally, distracting/interrupting elements were identified as antecedents to loss of SA in six of the 18 cases, for example the need to perform administrative tasks that drew attention away from the navigational equipment or surrounding environment.

The bridge on a ship represents a complex collaborative system in which highly specialized individuals operate navigational equipment and interact to perform safety-critical operations. Following from a systems ergonomics perspective, the bridge is a prototypical example of a system in which performance is closely dependant on interaction with and efficient use of tools, such as steering documents, checklists, and

¹ This term refers to vessels that provide services to offshore installations, such as platform supply vessels (PSVs), anchor-handling vessels, standby vessels, and oil tankers. Historical data indicate that 98% of collisions between vessels and offshore facilities on the Norwegian continental shelf involve attendant vessels (The North West European Area Guidelines, 2009).

² See Daley (2013) for a description of the Mumbai High North accident, in which a multipurpose supply vessel lost control and hit several marine risers on an offshore facility on the west coast of India. The collision caused a gas leak, which ignited and caused 22 fatalities.

technology. According to Stanton, Salmon, Walker, and Jenkins (2010), distributed situation awareness (DSA) is a salient characteristic of complex collaborative systems that can be defined as ‘activated knowledge for a specific task within a system at a specific time by specific agents’ (p. 34). Following from this perspective, it is important to examine interactions between agents (human and non-human actors), including interactions between individuals and interactions between individuals and tools, to describe how SA information is distributed and coordinated within the system (Salmon, Stanton, Walker, & Jenkins, 2009). In this study, we draw on the concept of DSA and extend the findings of the Sandhåland *et al.* (2015) study, which indicated that inadequate planning, communication failure, and interrupting/distracting elements are important antecedents to loss of SA. In particular, we wanted to increase our understanding of how interactions between agents in bridge operations on board a selection of PSVs are reflected in established practices related to planning, communication, and management of distracting/interrupting elements, and in turn, how shipboard practices affect the bridge teams’ SA needs.

Previous research has relied heavily on accident analysis to understand the complex individual and contextual factors that increase the likelihood of accidents in the maritime industry; however, accident analysis might overemphasize the unique and salient aspects of the situation because of distortion, self-serving bias, and decay of information over time (Macrae, 2009). In this study, we chose an ethnographic, true-to-life approach, sampling and assessing everyday situations on board a selection of PSVs.

Because a significant proportion of the work on board a PSV happens near offshore facilities, there is a risk of collisions with these facilities. For that reason, we put particular emphasis on shipboard practices related to safe approach and positioning of the vessels alongside the offshore facilities. We were especially interested in observing the planning and execution of operations alongside offshore facilities, the communication between bridge team members, and potentially distracting/interrupting elements that could have implications for the bridge teams’ SA.

Moreover, although the bridge teams’ SA could be influenced by factors independent of the bridge (e.g., if the team made decisions during coffee breaks or off-duty periods), our study was limited to practices at the bridge.

Theoretical foundation

Theories of SA

The concept of SA has been debated, and different approaches to studying SA have been suggested. From a psychological perspective, SA is understood as cognitive processes in the minds of individuals in a system. From a systems ergonomics perspective, SA is understood as a process that happens through interactions between individuals and the tools that they use to accomplish their goals (Stanton *et al.*, 2010). These two approaches to studying SA are further detailed below.

Within the psychological tradition, the most cited model of SA is Endsley’s (1995) three-level model. She suggested that an individual builds SA at three different levels. First (SA level 1), the operator perceives critical information that is relevant to his or her goals. In the context of safe navigation, this information may include factors such as the vessel’s operational status, the vessel’s positioning, and other approaching vessels. Second (SA level 2), the operator will integrate and evaluate the information at hand. She or he has to understand the perceived information in relation to relevant goals and objectives, such as safe approach to an offshore facility. Third (SA level 3), the operator uses his or her

perception and comprehension of the situation to forecast and estimate likely imminent outcomes, opportunities, or threats. For instance, by calculating speed, currents, and wind, the duty officer can avoid colliding with the offshore facility by taking manual control or reprogramming the automatic navigation systems.

Following from Endsley's three-level model, studies of SA involve examining the cognitive processes in each individual's mind. In contrast, the concept of DSA favours a system ergonomic approach to studying SA by considering the physical or social environment in which these cognitive processes occur. In accordance with the concept of *distributed cognition* (Hutchins, 1995), a central assumption in DSA is that SA information is held by different agents that comprise a collaborative system. An intriguing implication of conceptualizing SA as distributed cognition is that SA information is not only distributed within the team but also in the tools that they use to accomplish their goals (Salmon *et al.*, 2009; Stanton *et al.*, 2006). At the bridge on board a PSV, several tools provide the bridge team members with SA information including radar equipment, anemometers, wave riders, current and tide tables, weather forecasts, and steering documents. Following from this conceptualization, Stanton *et al.* (2006) proposed that DSA is a product of coordination among these agents such that the system itself holds the SA that is required to accomplish its goals. It is thus critical that the right information is transferred to the right team member at the right time in order for each individual to achieve and maintain the SA necessary for their function in the system (Stanton *et al.*, 2010). Thus, in contrast to the psychological approach to SA, a DSA approach views SA as a system property 'by consideration of the information held by the artefacts and people and the way in which they interact' (Stanton *et al.*, 2010, p. 34).

In maritime bridge operations, safe navigation and execution of cargo operations are the result of a team effort rather than the work of an isolated individual. From a psychological perspective, the concept of team SA, which is defined as 'the degree to which every team member possesses the SA required for his or her responsibility' (Endsley, 1999, p. 270), recognizes the different SA needs and requirements that are associated with different roles in a team. However, according to Endsley (2012), the degree of SA shared among the members in the team should be high. Although it may be intuitively appealing, the concept of shared SA is problematic because unique personal preferences, schemata, skills, and training influence each team member's perception of the situation. In response to these inherent difficulties, proponents of a DSA perspective have suggested that different team members have different roles and therefore need to comprehend and use information differently (Stanton *et al.*, 2010). It is further emphasized that the agents that comprise a collaborative system may have different but potentially compatible SA, depending on the role of each agent in the system (Stanton *et al.*, 2006).

A DSA approach to examining SA in collaborative systems does not imply that psychological approaches to studying SA are redundant; rather, DSA approaches provide an alternative and complementary view of SA in collaborative systems (Salmon *et al.*, 2008). We have adopted a DSA approach because this perspective captures more of the human-system interaction in complex operational systems such as PSVs. We also believe that this approach will enhance our understanding of the factors that influence the bridge team members' SA. The DSA perspective will further point to the potential value of using an ethnographic, process-oriented approach to investigate SA in complex collaborative systems.

Antecedents to SA

Previous research has identified factors that are believed to affect SA in operational settings. For instance, Sneddon, Mearns, and Flin (2013) found that stress, sleep disruption, and fatigue were associated with lower levels of work SA in a study of offshore drill crews. Endsley (2001, 2012) proposed that both system design (availability of information) and interface design (how information is presented) are important in SA. Factors such as training, knowledge, and skills are also important in regard to the bridge team's achievement and maintenance of SA in operational settings (Endsley, 1995; Espevik, Johnsen, & Eid, 2011). Planning activities, communication, and distracting/interrupting elements have also been suggested to influence SA. In the following sections, we will elaborate on these themes.

Planning. High-quality planning prior to performance of a task can reduce the risk of loss of SA because it can increase bridge teams' awareness of the risks that are associated with an upcoming task (Flin, O'Connor, & Crichton, 2008). If critical information provided by other agents is missed or misperceived, this miscommunication could lead to loss of SA and severe consequences. It is therefore particularly important that the bridge team pay close attention to planning. In particular, contingency planning – anticipating possible scenarios and threats – may contribute to consolidating and developing schemata and structural aspects of social tasks. Insofar as planning provides shared knowledge about the system, possible threats, and strategies, it may increase the likelihood of the bridge team achieving an SA that will facilitate individual and collective task performance (Mohammed, Ferzandi, & Hamilton, 2010).

Communication. In our observations of bridge teams at work, our point of departure was that interactions such as information sharing and interaction with technological equipment or the environment are vital for optimal system performance (Bolstad, Cuevas, Gonzalez, & Schenider, 2005). A notable aspect of this dependence is that communication failure is often reported to precede loss of SA because communication is commonly considered to be a key factor in connecting and maintaining the different parts of a distributed system (Stanton *et al.*, 2010). In analysing team communication, it might be helpful to distinguish between *information exchange* and *communication* to understand how practices can affect bridge teams' information needs. Thus, *information exchange* refers to the type of information that is transferred between the bridge team members. The transmission of critical information, such as the location of nearby vessels and the transfer of command during shift handover, is relevant for safe navigation. In contrast, *communication* refers to how the information is transferred between the bridge team members. Communication should involve the use of succinct and accurate terminology without circuitous language (Smith-Jentsch, Johnston, & Payne, 1998). In addition, it is critical to ensure that the information is understood. To this end, closed-loop communication, in which the receiver repeats the information and the sender confirms it, may be an effective technique (Bowers, Jentsch, Salas, & Braun, 1998).

Distracting/interrupting elements. Direct attention is necessary to perceive and understand received information (Endsley, 1995). Thus, the bridge team members' ability to sustain attention is a critical dimension. In operational settings, the flow of information

between agents can be complex and dynamic, which makes operators vulnerable to distractions and interruptions (Endsley & Robertson, 2000; Flin *et al.*, 2008; Robertson & Endsley, 1995). Distracting and interrupting elements can stem from various sources, such as incoming telephone calls or other crew members, and they increase the strain on limited attention resources (Loukopoulos, Dismukes, & Barshi, 2009).

System description

In addition to national regulations, international conventions, and shipping companies' safety systems, the North West European Area (NWEA) guidelines for the safe management of offshore supply and anchor-handling operations³ provide structured recommendations to assist bridge teams in their day-to-day operations. The NWEA guidelines were developed as a joint project between maritime and offshore organizations in Denmark, the Netherlands, the UK, and Norway to incorporate best practices in offshore supply and anchor-handling operations in the industry (The North West European Area Guidelines, 2009). Although the guidelines have the status of recommendations, vessels that provide supply services to the offshore industry must comply with the guidelines according to client requirements. The NWEA guidelines note possible dangers, encourage vigilance, and prescribe a systematic, data-driven approach to safe navigation. In effect, the guidelines shape the bridge teams' assessment and comprehension of situations and prescribe best practices. Therefore, the NWEA guidelines constitute a common framework for establishing SA during offshore operations.

The bridge team on board a PSV usually consists of four officers divided into two shifts. The chief officer and the master are usually on separate shifts and are paired with an officer of lower rank. In addition, cadets are occasionally added to the bridge team for training purposes. The offshore facilities are protected by a safety zone with a radius of 500 metres, and access to the offshore facilities requires permission from the offshore facility's control room. Whenever the vessels operate inside the safety zones, the NWEA guidelines mandate that the bridge be manned with two officers or, alternatively, one officer and a cadet with a bridge-watch certificate; however, sailing between port and the offshore facilities is frequently performed with a single officer present on the bridge. Before the vessels are given permission to enter the offshore facilities' safety zones, the bridge teams must confirm that mandatory checklists have been completed. These checklists concern the vessel's technical status, assessment of weather conditions and communication lines, and other items. According to the NWEA guidelines, loading/offloading operations alongside the offshore facilities should, to the greatest extent possible, be performed on the leeward side to ensure that if a vessel experiences any technical problems, it will be in a drift-off position and thus avoid colliding with the offshore facility.

The bridge team on board a PSV employs a variety of tools to navigate safely, but the vessels included in our study had different bridge arrangements regarding the placement of tools and the interior of the bridge. Figure 1 depicts a typical bridge.

Loading/offloading operations alongside the offshore facilities are performed from the stern steering position and usually through dynamic positioning (DP). DP is an advanced automated manoeuvring system that is based on positioning reference systems such as global positioning systems. The DP system requires minimal intervention by the bridge

³ The NWEA guidelines were replaced by *Guidelines for Offshore and Marine Operations (GOMO)* on 1 June 2014. However, the NWEA guidelines remained in effect at the time this study was conducted.

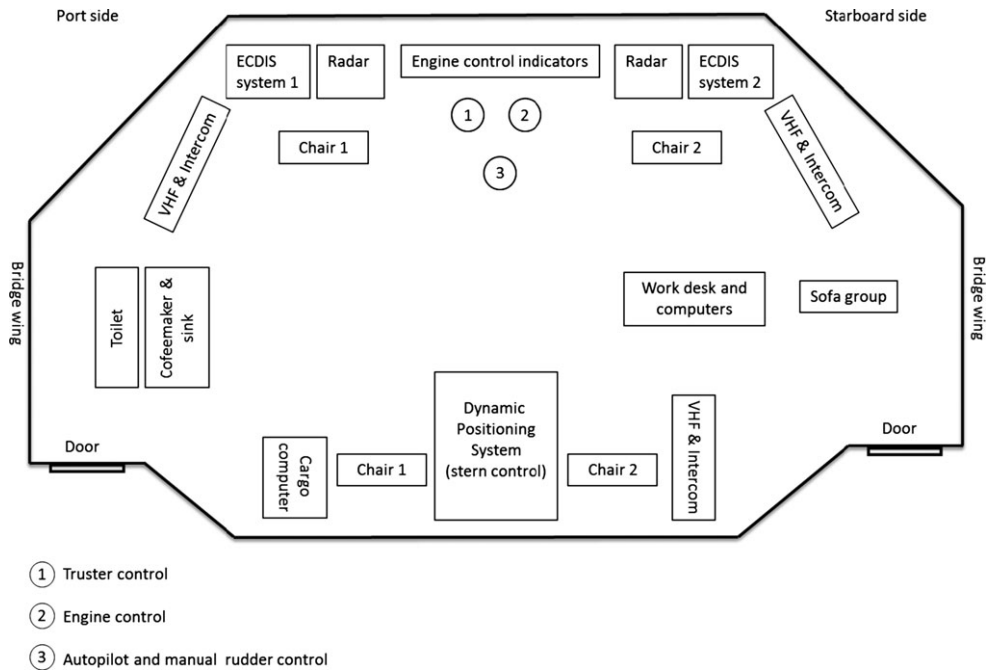


Figure 1. Sketch of a typical bridge on board a platform supply vessels (PSV).

team to keep the vessel in a fixed position; the main task for the bridge team is to monitor the technical system and surrounding environment and take action as needed. During loading/offloading operations, both officers were positioned at the stern steering position. The normal division of responsibility is that the DP operator is responsible for navigational activities, whereas the other officer is responsible for the loading/offloading operation, communication with other actors, and supporting the DP operators that are engaged in monitoring. Sailing back and forth between port and offshore facilities, in addition to between offshore facilities, was usually performed using autopilot from the forward steering position. All of the vessels used the Electronic Chart Display and Information System as an alternative to paper nautical charts. In addition to electronic chart information, the system integrates information that is provided by an automatic identification system, such as other vessels' positions, heading, and speed, and generates alarms when the vessel faces a risk, such as a collision with another vessel. The vessels were also equipped with radar systems that use radio waves to detect objects in the fairway. In addition, available control panels provided various indicators related to the vessels' technical systems, such as engine-control indicators.

Method

A theory-driven ethnographic approach

A critical challenge in ethnographic studies is the choice of a focus because the researcher simply cannot observe everything. A theoretical proposal is needed to guide data collection (Willis & Trondman, 2002; Yin, 2009). In this respect, this study builds on concepts at several levels of abstraction. First, the concept of DSA allows us to examine practices to describe how SA information is distributed and coordinated on the bridge.

Second, the selected themes (i.e., planning, communication, and management of distracting/interrupting elements) connect to DSA in that they refer to interactions among agents that comprise the system. These activities are also believed to influence the bridge team's ability to achieve and maintain SA. Finally, this study required more accurate concepts within each theme, which we termed 'observable practices' (e.g., planning of the approach to the offshore facility, communication related to the transfer of command, and conduction of administrative tasks during navigational activities), to focus on situations that are relevant to the PSV setting. In this process, we drew on findings from previous studies of collisions between attendant vessels and offshore facilities (Kvitrud, 2011; Oltedal, 2012; Sandhåland *et al.*, 2015), along with information derived from a preparatory field trip on board a PSV and informal conversations with navigators. Concepts were selected based on previous research and the informed opinions of practitioners regarding critical components of safe navigation on board a PSV. Together, these concepts served as a framework that gave the study direction.

Sample descriptions

The fieldwork was conducted on board four PSVs that belong to two Norwegian-controlled shipping companies. Both shipping companies were selected based on their extensive experience in providing supply services to the oil and gas industry. PSVs were chosen because they are the type of vessel that most frequently approaches offshore facilities. The vessels included in the study were state-of-the-art PSVs built between 2003 and 2012. With some variations, a typical vessel was 90 m long and 20 m wide and carried 5000 tonnes of deadweight tonnage. The crew members had private cabins and shared off-duty recreational facilities, such as fitness equipment, television, and internet facilities. The rotation arrangement was 4 weeks at work and 4 weeks off on all of the vessels. All of the vessels were on long-term charters to three different oil companies. Two of the vessels operated on the Norwegian continental shelf, and the remaining two operated on the UK continental shelf. Apart from some vessel-specific adjustments to the checklists, both shipping companies had to follow the NWEA operational guidelines. All four vessels aimed to supply the offshore facilities in an efficient and safe manner.

A total of 18 bridge team members (15 officers and three cadets) from eight shifts were included in this study. All participants spoke Norwegian fluently and, except for one participant, all had trained at Norwegian educational institutions.

Data collection

Each fieldwork period lasted for between 8 and 14 days, with an average attendance on the bridge of approximately 10 hr a day. Approximately 450 hr of observational data were collected for the study. The fieldwork was conducted over a 1-year period from October 2012 to October 2013.

To minimize disturbance to the operations performed at the bridge, only one researcher worked on board the vessels. The researcher who conducted the field work has a theoretical background in risk and safety management and has also worked with safety issues in the oil and gas industry.

Several studies have highlighted the importance of trust and cooperation for the collection of accurate and dependable data in fieldwork (Aase & Fossåskaret, 2007; DeWalt & DeWalt, 2011; Fangen, 2005). In this respect, a role that was consistent with Gold's (1958) 'participant-as-observer' was adopted. That is, the researcher followed the crew in

their day-to-day activities and spent more time participating and interacting with the crew members than observing from a distance. In practice, this involved informal conversations and asking questions when the crew members were available. In addition, the researcher observed how the bridge team members interacted with each other and with other entities to gain first-hand experience of naturally occurring events and some familiarity with the underlying operational procedures. The bridge teams also demonstrated how the equipment on the bridge (e.g., the DP system and position reference systems) worked, thereby providing the opportunity to further elaborate on technical information that emerged during conversations and observations. The researcher also asked questions related to observations. For instance, when the bridge team positioned the vessel alongside the offshore facility without any prior overt discussion, the researcher might have asked ‘What type of assessment did you do when you made this particular approach?’

Some theorists have suggested that writing field notes in view of the informants might strain relationships with the researcher and distract the researcher in the field (Emerson, Fretz, & Shaw, 1995; Fangen, 2005). Field notes were therefore written in between the observation periods. The researcher withdrew to the cabin several times a day or immediately after significant events to record observations. Observations and quotations presented in this study are excerpts from the researcher’s field notes. Thus, the reader should be aware that observations and quotations are as remembered by the researcher.

Processing and presentation of results

Initially, observations and quotations were systematized according to the concepts in the framework. We thereby used a ‘provisional coding’ method, in which codes were generated from investigations performed prior to the fieldwork (Saldaña, 2009). Thereafter, the data were re-examined, and the initial categories were refined. Finally, the data were re-examined to identify similarities and differences between vessels. The coding of the field notes was performed by the first author, who also performed the field work. The findings were discussed with experts in navigation and safety sciences throughout the coding process.

The representational style of this study might, according to Van Maanen’s (2011) classification of voices of the field, be characterized as a ‘realist tale’. We present our findings as concrete images of shipboard practices on the bridge that are related to planning, communication, and management of distracting/interacting elements. The researcher’s experience in the field is not highlighted; rather, the story that we tell conveys concrete descriptions of what the bridge teams do and say and is organized according to our selected themes and observable practices.

Each vessel and informant was assigned a code to identify their observations and quotations. The vessels are coded V1, V2, V3, and V4; officers are given the codes O1, O2, O3, and O4; and cadets are given the codes C1 and C2, which are in turn linked to their vessel (e.g., V1-O3 and V3-C1). Occasionally, it was necessary to refer to a particular shift; shifts are coded as S1 or S2 and similarly linked to the vessel (e.g., V1-S1).

Methodological challenges

We hope that the above chapter convinces the reader that ethnography is a useful methodological approach in this context; however, all methodological approaches have limitations. In this section, we will concentrate on the major limitations that we believe influenced our findings. First, the relationship between the researcher and the bridge

team may have influenced the findings in several ways. Structurally, the researcher inhabited an ‘unknown’ position in that all bridge team members had clear rights and duties in relation to each other, but the researcher was an outsider with no clear rights and duties in relation to the vessel. This position may have caused some uncertainty both about the researcher’s role on board the vessel and the aims of the study. Additionally, the researcher’s presence may have influenced the bridge team’s behaviour. Statements such as ‘I have to say, you do the checklists thoroughly when she [the researcher] is present’ (V4-O3) suggest that the researcher’s presence promoted increased use of checklists and other steering documentation. Second, the researcher’s lack of a nautical background is important in terms of the researcher’s understanding of the system. In a high-tech expert-run system, such as a PSV, outsiders are unlikely be able to fully understand the ongoing processes. The use of highly specialized terminology and tacit agreements among the bridge team members may also have impeded the researcher’s understanding.

Results

In the following sections, we describe how shipboard practices related to planning, communication, and management of distracting elements were realized in day-to-day operations. Regarding planning activities, we focus on planning of the approach to the offshore facility and contingency planning related to operations alongside the offshore facility. In regard to communication practices, we focus on communication between bridge team members during completion of checklists, transfer of command, DP operations, and changes in the vessel’s manoeuvring position. Finally, distracting and interrupting elements are examined in terms of interference with administrative tasks, use of electronic devices, and non-essential conversations.

Planning practices

The NWEA guidelines underscore the importance of the planning phase before vessels enter an offshore facility’s safety zone (The North West European Area Guidelines, 2009). In this phase of the voyage, the bridge team uses a variety of information provided by assorted agents to make a safe approach and position the vessel alongside the offshore facility. This information includes, but is not limited to, information about environmental forces provided by tools (e.g., anemometers, wave riders, current and tide tables, and weather forecasts), information provided by the offshore facility regarding operational conditions on board the offshore facility (e.g., positioning and range of cranes, potential anchor chains, heading, and flaring), and information provided by the technical equipment on board the vessel regarding the vessel’s technical status and loading plans regarding the positioning of cargo on deck. The following sections present observations and quotations to illustrate findings that relate to pre-entry safety planning, including contingency planning.

Planning of approach

On one of the vessels (V2), the senior officer on both shifts initiated active discussions about how to approach and position the vessel alongside the offshore facilities. The following narrative describes a conversation between a senior officer and his junior officer prior to approaching the offshore facility and positioning the vessel:

A senior officer and his junior officer have different suggestions about how to approach and position the vessel alongside the offshore facility. The senior officer asks the junior officer to state the arguments for his viewpoint. Subsequently, the senior officer suggests a different solution and adds that they have always performed it like that. The junior officer then replies 'I don't care if you have performed it like that for the last 100 years, there may be better solutions', to which the senior officer replies 'You're right. Let's do it your way.' After a while, once the vessel is well positioned alongside the facility, the senior officer comments, 'It was a good idea to position it like this.' (V2-O1 and V2-O3)

In the situation outlined above, different solutions for how to approach and position the vessel are proposed. On the remaining three vessels (V1, V3, V4), planning practices varied; however, planning for the approach and positioning very often took the form of a brief exchange and tacit agreement among the bridge team members, as follows: Officer V3-O1: 'Which side do they [the offshore facility] prefer?' and Officer V3-O3: 'The east side.' Little additional verbal communication occurred among the bridge team members, thereby implying that these assessments and the subsequent decision regarding the situation occurred in each individual's mind, without explicit communication about procedures. The differences in planning practices among the vessels seem to be associated with shipboard leadership and the associated training philosophy. The senior officers on board the vessel that held overt discussions frequently encouraged the junior officers and cadets to express their viewpoints, as supported by an observation in which one senior officer listened to the discussion between a junior officer and his cadet regarding how to approach and position the vessel. The senior officer did not interfere in the discussion before they finished; afterwards, he asked them to state the arguments in support of their decision. Based on the ensuing discussion, the initial plan was adjusted (V2-O2, V2-O4, and V2-C1).

Contingency planning

Although all known risk factors were considered and the vessel was well positioned, unforeseen events such as technical failures remain possible. Several of our informants expressed concerns about this possibility:

As a DP operator, I constantly think about what might go wrong and what to do if anything should happen (...) we often talk about how important it is to think through what might happen and how to address the situation if the worst-case scenarios should ever materialise. (V1-O1)

No explicit discussions of such scenarios were witnessed, thus indicating that contingency planning was primarily performed as an individual activity rather than as a team activity on board the vessels; however, one of the participants had a different opinion:

It is not possible to keep in mind what could go wrong at all times—then it is impossible to work. If, for example, we have positioned the vessel on the weather side, wind limitations are within requirements and you have enough engine power, then you just have to rely on your equipment—living is dangerous as well. If we are positioned on the downwind side, then there is nothing to worry about anyhow. (V3-O2)

This quotation indicates that there are other views regarding the value of contingency planning.

Communication practices

Operations on board a PSV require interaction among various agents, both on board the vessel and on the offshore facility. For the bridge team to gain access to safety-critical information, it is important that the information is communicated in a clear and unambiguous manner. The overall picture shows great variation in communication practices on board the vessels. In the following section, we provide examples of communication related to the completion of checklists, transfer of command, and DP operations alongside offshore facilities, including switching between the vessel's manoeuvring positions.

Completion of checklists

The bridge teams have mandatory checklists that are available during the planning of an approach that can support their awareness of critical information before the vessel enters the safety zone. The pre-entry checklist has checkpoints for the vessel's operational status, communication lines with the offshore facility and other departments on board, and weather conditions, among other items. If the vessel is preparing for DP operations, an additional checklist that pertains to the operational status of the DP and its backup systems must also be completed. However, communication among the bridge team members during the completion of checklists varied considerably between vessels. On one vessel (V1), Officer A cited the items in the checklists, whereas both Officer A and Officer B checked the system independently and reported on the items. On another vessel (V2), Officer A cited items in the checklist, whereas Officer B checked the system and reported back to Officer A. On the two remaining vessels (V3 and V4), the method for completion of the checklists depended on the officer on duty. The general rule on these vessels was that the checklists were performed by a single officer, either without any communication with the other officer or with two-way communication about some of the items. The following is an example of the latter:

The vessel is heading towards the offshore facility's safety zone, and the cadet is completing the 500-metre pre-entry checklist. He is reading some of the items aloud, and the officers reply with a yes or no. When he reads the item 'autopilot off', the two other officers both reply 'not yet.' The cadet continues with the rest of the items. Meanwhile, there is a shift handover and, as part of the handover, the cadet informs the oncoming shift that 'the 500-metre checklist is completed, everything OK'. (V3-S1)

No further information regarding the status of the autopilot was exchanged. In addition to providing an example of how the checklists were completed on board the vessel, this situation also demonstrates that the checklist was started and completed by the bridge team that was going off shift rather than the shift responsible for the approach and positioning alongside the offshore facility.

Some participants, especially the less experienced officers, stated that they regarded the checklists as useful tools, whereas others emphasized that they would complete the listed tasks with or without the checklists. Checklist activities were occasionally completed by memory, independent of the paper copy and without communication with other bridge team members.

Transfer of command

Everyone must have a clear understanding of which officer is in command of the vessel at any given moment. To this end, transfers of command must be made explicitly. Such transfers occur both between shifts and during the shift. During shift handovers, the transfer of command was, as far as it was observed on all the vessels, performed using the statements 'good watch' and 'good watch below'. This was performed after necessary operational and safety-critical information had been given to the oncoming shift; however, explicit communication is important when command is transferred between and within shifts. For instance, on two of the vessels (V1 and V2), both the chief officers and the masters frequently approached the bridge even when they were off duty. Although there seemed to be a common understanding regarding who was in command, their interactions with the duty officer on watch appeared to create situations with a potential for confusion. The following passage describes a situation on board one of the vessels:

The vessel is on autopilot heading towards port. The officer on watch leaves the control stand in order to make coffee and perform some minor routine tasks. The master of the vessel, who has already entered the bridge, positions himself by the control stand. No explicit information exchange about the command of the vessel or about the vessel's operational status occurs. When the officer on watch finishes his duties, he joins the master at the control stand, where they both remain for a while—until the master leaves the bridge. (V1-O1 and V1-O4)

In the situation outlined above, command issues seem to be based on tacit agreement rather than a clear and unambiguous transfer of command. In addition, no information regarding the voyage was exchanged before the officer on watch left the control stand.

DP operations and changes in the vessel's manoeuvring position

During DP operations alongside the offshore facilities, misperceptions and misunderstandings may have serious consequences. In such operations, the responsibilities of the officers are normally predefined such that one is responsible for the DP operation, whereas the other is responsible for loading/offloading, communication with other parties, and support for the DP operator's monitoring responsibilities. Because the vessels are equipped with two DP stations, both officers have access to navigational equipment and communication devices. On most of the observed shifts (V1-S1, V2-S1, V2-S2, V3-S1, V4-S2), the predefined division of responsibility seemed to be followed; however, on three shifts (V1-S2, V3-S2, V4-S1), frequent deviations from the predefined division of responsibility were observed. Observations from two of the shifts (V1-S2 and V4-S1) are relevant to communication because they indicate that the officer responsible for loading/offloading sporadically acknowledged pre-warnings on the DP system that indicated that the vessel's location deviated from the DP set point. Such warnings are indicated not by an audible alarm but rather by text and a colour code on the DP screen. In these cases, the pre-warnings were acknowledged without communication of the action to the DP operator.

When vessels operate on DP, their steering mode is transferred from the forward manoeuvring station to the DP station that is positioned aft. Thus, changes in the vessel's manoeuvring position can represent a risk (The North West European Area Guidelines, 2009). Until the transfer and takeover of command are acknowledged from the other steering position, the bridge team is not in control of the vessel's movements. On two of

the vessels (V3 and V4), this operation was primarily performed by a single officer, thereby making communication irrelevant. On the remaining two vessels (V1 and V2), the transfer of the manoeuvring position was performed by two officers – One at the forward manoeuvring station and the other at the aft manoeuvring station. On these vessels, the transfers were, as a general rule, performed using a standardized communication procedure: ‘All controls set to neutral position—are you ready?’ and ‘All controls set to neutral position—I am ready.’ With only minor changes in the wording, this communication was consistent on one of the vessels (V2). On the other vessel (V1), the bridge team occasionally deviated from this standardized communication. The following passage describes one of those situations:

The vessel has completed its loading/offloading operation and is about to exit the offshore facility 500-metre safety zone. The following describes the communication during transfer of manoeuvring control: Officer A, who is positioned aft, asks: ‘Do you want her?’ whereupon Officer B at the forward position answers: ‘Yes.’ A few seconds after transfer of control, Officer A mumbles, ‘There is something wrong here’, and at the same time, Officer B shouts, ‘Deactivate the thrusters!’ Officer A then replies, ‘I cannot do it.’ Subsequently, Officer B joins Officer A at the aft position and, within a few seconds, they have sorted out the problem. (V1-O1 and V1-O2)

It turned out that their problems were caused by the controls, which were not set in the neutral position; this, in turn, caused unexpected movements. It is reasonable to assume that the use of standardized communication would have created greater awareness regarding the status of the technical system.

Interruptions and distractions

Most professionals manage interruptions and distractions on a daily basis, and bridge teams on board PSVs are no exception. In addition to navigation, the bridge teams have to manage radio communication and incoming telephone calls, among other things. Although interruptions and distractions are an essential part of bridge operations, their potential negative consequences for safe navigation should not be ignored. We focused on interrupting and distracting elements that originate from ‘non-task-related’ factors, that is factors that were not related to an ongoing operation. The most prominent factors were related to concurrent task management, such as administrative tasks, the use of electronic devices, and informal, non-essential conversations. We will elaborate on these findings in the following sections.

Administrative tasks

Some participants stated that the number of administrative tasks did not influence their ability to attend to navigational activities because there was a sensible allocation of tasks among the bridge team members; this claim was also supported by observations. However, other participants indicated that the number of administrative tasks on board the vessel challenged their ability to fulfil their navigational responsibilities. The following passage describes one of those situations:

One of the officers is alone on the bridge, and the vessel is on autopilot heading towards port. Located in the administrative area of the bridge, the officer is busy updating maritime documents. In that position, he had a limited view of both the control stand and the

surrounding environment. According to the officer, 'I have to do this when we are sailing because I don't have time to do it in port; on the other hand, when we are sailing, I am supposed to navigate. If we get audits, they won't let us leave until it [the paperwork] is done. Now I am two weeks behind and have to finish before we reach port.' (V1-O4)

In the situation outlined above, no one was paying attention to the technical system or the fairway for a long period of time, which was not typical. However, other participants also expressed concerns about the number of administrative tasks in relation to their ability to perform navigational tasks:

When we are leaving port, we are far at sea before we have finished the paperwork. We are supposed to finish before we leave port, but that is not the case. I would have preferred that he [the second watch officer] was looking out of the windows instead of doing paperwork. (V3-O1)

In the statement above, the informant is suggesting that the intended organizational redundancy of manning the bridge with two persons is decreased because of administrative requirements during a demanding phase of the voyage.

Electronic devices

Other disturbing elements, such as the use of private mobile phones and personal computers, could also be characterized as distracting elements in this context. Major differences were observed both among the vessels and between shifts on each vessel, ranging from few or no observations on many of the shifts (V1-S1, V1-S2, V2-S1, V2-S2, and V3-S1) to the extensive use of such devices by some shifts (V3-S2, V4-S1, and V4-S2). The use of electronic devices on the bridge seems to be associated with age: It mainly involved the youngest crew members. It also seems to be associated with shipboard leadership, because minutes from HSE (Health, Safety and Environment) meetings indicate that the use of such devices had previously been an issue on board a vessel (V1) on which no such observations were made in this study. The minutes stated that the use of personal electronic devices was prohibited on the bridge.

Non-essential conversations

To maintain attention during periods of low workload, conversation might be necessary; however, conversations could distract from the bridge team's monitoring tasks. The following passage describes the context of a conversation that took place on one of the vessels:

The vessel is positioned for its loading/offloading operation in close proximity to the offshore facility. The officer whose responsibility it is to operate the DP system is conversing about personal issues with another crew member who is off duty. The upper part of the DP operator's body is turned towards the other crew member (sideways in relation to the DP station), and he (presumably) switches his attention back and forth between the DP station, the surroundings and his off-duty colleague. (V1-O2)

Does this conversation distract from the DP operator's monitoring tasks? According to one of the vessel's officers, it does not:

At the same time, the researcher and another officer are conversing on a topic related to technology and attention demands [on another part of the bridge]. During the conversation, the officer says, 'It takes a lot experience to converse like he is doing [points towards the DP operator] and still be able to operate the DP.' (V1-O1)

In the situation outlined above, the officer emphasizes the importance of experience for the ability to manage multiple tasks. Similar situations were observed on the other vessels. In general, access to the bridge does not seem to be restricted, thereby increasing the risk of distractions and interruptions by other crew members.

Summary of findings

This study presents new empirical information about how shipboard practices regarding planning, communication, and management of interrupting/distracting elements are realized in real-world settings on board four selected PSVs. Several practices highlighted in our study were observed in all of the vessels: Contingency planning as an individual activity, distractions/interruptions due to non-essential conversations, and limited use of standardized communication during transfer of command. It is worth noting that the two vessels that practised two-way communication when completing the checklists had limited or no use of personal electronic devices on the bridge and practised standardized communication during the transfer of the steering position belonged to the same shipping company.

In the following sections, we will discuss the findings summarized in Table 1 in the light of the theoretical concept of DSA.

Discussion

Planning practices

Prior to the decision of how to approach and position the vessel alongside the offshore facility, information has to be collected from agents in the system, including anemometers, wave riders, current and tide tables, and weather forecasts. This information is

Table 1. Summary of findings

Themes	Observable practices
Planning	Planning of approach as an individual activity: V1 (*), V2 (-), V3 (*), V4 (*) Contingency planning as an individual activity: V1 (+), V2 (+), V3 (+), V4 (+)
Communication	Completion of checklists as an individual activity: V1 (-), V2 (-), V3 (*), V4 (*) Limited use of standardized communication during transfer of command: V1 (+), V2 (+), V3 (+), V4 (+) Inadequate transfer of information during DP operations: V1 (*), V2 (-), V3 (-), V4 (*) Limited use of standardized communication during transfer of manoeuvring position: V1 (*), V2 (-), V3 (+), V4 (+)
Distractions and interruptions	Administrative tasks: V1 (*), V2 (-), V3 (+), V4 (+) Electronic devices: V1 (*), V2 (-), V3 (+), V4 (+) Non-essential conversations: V1 (+), V2 (+), V3 (+), V4 (+)

Note. (+), could find; (*), found a tendency; (-), could not find.
DP, dynamic positioning.

crucial for the bridge team's ability to choose the safest strategy. This study revealed notable differences in planning practices, ranging from overt discussions to an implicit agreement among the bridge team members. Because SA information is held by different team members, they must share information to achieve an adequate understanding of the situation. There are thus some compelling arguments in favour of planning as a team activity. First, it is a reasonable assumption that planning as a team activity facilitates exchange of information that is relevant to SA. Second, because each team member has a different perspective on the world, they have to interact to help each other in making sense of their perspectives including how wind, waves, and currents, in combination with the vessel's technical status, will affect the vessel. Through collaboration, they can construct a more complete understanding of the situation than would be available to any individual alone (Weick, 2005). In other words, planning as a team activity may bolster safety by increasing the likelihood of relevant information being transferred and properly assessed by the bridge team prior to the operation.

Whenever the vessel is positioned alongside the offshore facilities, there is limited time to act if something unforeseen should occur. Technical faults, loss of signals to the positioning reference systems, and sudden changes in weather conditions are examples of unforeseen events that could lead to severe consequences without immediate mitigating actions. It is therefore particularly important that the bridge team be cognizant of potential threats and disturbances likely to act on the system and have an idea of how to act if the worst-case scenarios should materialize. In a DSA perspective, it is emphasized that each agent's SA should be compatible in a manner that binds collaborative systems together (Stanton *et al.*, 2010). Although the officer in command is responsible for the safe approach and positioning of the vessel, the co-pilot should be able to provide support whenever needed. Contingency planning as a team activity prior to the operation may therefore facilitate a shared understanding of potential threats and disturbances. We acknowledge, however, that shared SA is problematic because personal differences in schemata, skills, and training influence how information is processed. Nonetheless, there remains a need for shared information when the bridge team members have overlapping responsibilities. A high degree of shared knowledge about potential threats and disturbances may facilitate and promote coordinated actions in stressful situations, when decisions must be made rapidly.

Communication practices

Checklists are important tools in the planning stage prior to entering an offshore facility's safety zone. From a DSA perspective, checklists are an important tool for ensuring that SA-relevant information is transferred within the system. Although checklists do not contain SA-relevant information, they can be used to ensure that SA-relevant information is retrieved. The maritime industry often looks to the aviation industry for guidance regarding the use of checklists. In the aviation industry, checklist are used when configuring the plane. Two of the stated objectives that are generally highlighted are to 'allow mutual supervision (cross checking) among crew members' and to 'enhance a team (crew) concept (. . .) by keeping all crew members "in the loop"' (Degani & Wiener, 1993, p. 347). To meet these objectives, the manner in which the checklists are completed is relevant. Surprisingly, significant variation in the use of checklists on board the vessels was observed. Although practices on some of the vessels allowed for mutual supervision and/or keeping both bridge team members informed, other vessels did not seem to utilize this potential because the checklists were generally completed by a single officer or a

cadet. In addition, checklists were sometimes conducted by the bridge team that was going off shift rather than the bridge team that was responsible for safe navigation. In such cases, the checklists did not ensure information exchange between external agents (e.g., technical equipment and the offshore facility) and the officers that depended on the information to achieve SA for the task at hand. This practice may indicate a false sense of security in that completing checklists becomes a task rather than a safeguard.

Previous research lends support to the idea that higher-performing teams transfer information between team members to a greater extent than lower-performing teams (Westli, Johnsen, Eid, Rasten, & Brattebo, 2010). It follows from a DSA perspective that each team member's SA should be compatible for the system as a whole to function well (Stanton *et al.*, 2006). Considering that the situation on board a PSV is dynamic and involves extensive flow of information, accurate information exchange among bridge team members is especially important. In particular, information exchange must support each officer's SA needs regarding their function in the team. An example highlighted in this paper concerns observations that indicated that the co-officer acknowledged pre-warnings in the DP system without transferring the potentially essential information to the DP operator. In this case, the DP operator's SA could have been affected by shortcomings in information exchange.

Practices related to the transfer of command were also highlighted in our study, both during shift handover and during shifts. For the officer in command to acquire the information necessary for his/her SA, an exchange of information about the vessel's operational status must precede the transfer of command; however, our observations indicate that command was occasionally transferred during a shift without such an exchange. Although the information is available from tools at the bridge, such as monitors and control panels, verbal exchange is conducive to intuitive understanding. A practice that allows technology to dominate exchanges of information may therefore delay the duty officers' achievement of SA. It is a reasonable assumption that consistent transfer of operational information, both during and between shifts, will reduce the likelihood of misunderstandings.

According to Smith-Jentsch *et al.* (1998), there is a distinction between information exchange and communication: A critical dimension of communication is *how* information is exchanged. The use of standard communication phrases is one of the most important factors in communication in safety-critical organizations. This practice enables quick and effective communication while simultaneously reducing the likelihood of misunderstandings (International Air Transport Association, 2011). Standard Maritime Communication Phrases (International Maritime Organization, 2005) include, for instance, standard communication phrases for the transfer of command on the bridge; however, the use of standardized phrases to indicate the transfer of command, such as 'You are now in command' or 'I am now in command', was not observed. This finding was surprising because their use is proposed in the Standard Maritime Communication Phrases. The usefulness of such phrases is further emphasized by the fact that confusion about the transfer of command was a contributory factor in two cases of collisions between attendant vessels and offshore facilities on the Norwegian continental shelf in the last decade (Oltedal, 2012). Our observational findings suggest that the limited use of standard maritime communication phrases and closed-loop communication during transfer of command might increase the risk of misunderstandings regarding each team member's role and responsibilities.

Interrupting and distracting elements

Interruptions and distractions pose a serious threat because of their impact on the distribution of the team members' attention. In previous studies in the maritime industry (Grech, Horberry, & Smith, 2002) and other industries (e.g., Jones & Endsley, 1996; Sneddon, Mearns & Flin, 2006), failure to monitor or observe was the most common cause of loss of SA. In other words, inadequate transfer of information between the operator and other agents in the system preceded loss of SA. Our observations and statements from the PSVs indicate that concurrent task management was frequent and that it occasionally shifted attention away from the bridge team's responsibilities to monitor other agents in the system (e.g., monitors and the surrounding environment). Concurrent non-essential tasks highlighted in this study include administrative tasks, use of electronic devices, and non-essential conversations. These tasks were conducted while the bridge team had important monitoring responsibilities related to both the technical equipment and the surrounding environment. Whereas some of the informants described conflicting requirements between administrative tasks and navigational responsibilities, we have no data that could explain why they chose to let other disturbing elements interfere with their navigational responsibilities. However, it is a reasonable assumption that if the DP operator turns his/her back on technology for long periods, trust in technology might be an influencing factor.

Regardless of whether disturbing/interrupting elements arise from the need to complete administrative tasks, the use of electronic devices, or non-essential conversations, they require attention and cognitive resources. Although the officers frequently directed attention towards their monitoring tasks, distractions might still have significant implications for the bridge teams' SA requirements. Even if attention is shifted in a timely manner, additional cognitive effort is required to update SA (Loukopoulos *et al.*, 2009). This problem is recognized in the aviation industry, in which the 'sterile cockpit' rule was implemented after a series of aviation accidents. The rule prohibits the crew from performing non-essential duties and conducting non-essential conversations in specific safety-critical situations (Sumwalt, 1993). The maritime industry has also acknowledged the risk associated with interruptions and distractions. For instance, the NWEA guidelines state that during the planning stages and approach to offshore facilities, all non-essential tasks should be stopped or delegated (The North West European Area Guidelines, 2009). From a DSA perspective, this practice makes sense because it is critical to eliminate factors that can hamper timely and adequate transfer of SA-relevant information in day-to-day operations.

Conclusions

By consideration of the physical and social environment that surrounds the bridge team, DSA models acknowledge that SA-related information is held both by human and by non-human agents in the system, such as DP, Electronic Chart Display and Information Systems, wind riders, and documents. SA is thus considered to be a system property rather than an individual property. Because both human and non-human agents comprise a network, in which each agent holds SA-specific information, each agent's SA is constantly modified and updated through information exchange and interactions with other agents, including the technological environment. In this manner, a DSA approach better captures the dynamic characteristic of complex collaborative systems than individual approaches to SA. The bridge of a PSV represents a typical collaborative system in which bridge team members interact with each other and with external agents in a high-tech environment. To our knowledge, no previous studies have examined SA as a distributed phenomenon in

the maritime industry. Our study is particularly relevant because the paper provides a description of conditions that may influence the bridge teams' SA in day-to-day operations, and adds to our understanding of SA as a distributed phenomenon. By noting possible areas for improvements regarding planning activities, communication practices, and management of distracting/interrupting elements, the study provides an opportunity for the maritime industry to establish shipboard practices that meet the bridge team's information needs in a complex environment. The study might also provide a window into studying SA as a distributed phenomenon in other industrial settings; additionally, because planning, communication, and management of interrupting/distracting elements are essential tasks in many collaborative systems, our findings may have implications for other industrial settings as well.

Our findings may have practical implications for increasing DSA and reducing the risk of adverse outcomes during bridge operations. First, we argue that planning as a team activity may increase the likelihood that SA information will be shared and properly assessed, because team members may possess different information. Second, communication emerges as a key factor in connecting and maintaining the parts of a distributed system. It is therefore important that communication practices facilitate efficient and reliable transfers of information between agents through increased use of closed-loop and standardized communication. Finally, because achievement and maintenance of SA require focused attention, management of interrupting/distracting elements is important. Impaired attention may delay awareness of information provided by other agents, which may in turn affect the bridge team's SA needs.

Acknowledgements

The authors wish to thank the shipping companies that made it possible to conduct the study and, in particular, the crew on board the vessels for willingly sharing their knowledge and experience. The authors also wish to thank the staff at the Department of Maritime Studies at Stord/Haugesund University College for contributing valuable knowledge about navigation and the maritime industry.

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Received 10 March 2014; revised version received 9 February 2015