TransNav
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 11
Number 2
June 2017

DOI: 10.12716/1001.11.02.11

Distributed Situation Awareness in pilotage operations: Implications and Challenges

A. Sharma & S. Nazir
University College of Southeast-Norway, Borre, Norway

ABSTRACT: Pilotage is considered as the most critical leg of navigation and a complex operation in maritime domain. In this paper, we argue that Distributed Situation Awareness (DSA) is an important construct in pilotage as the information required to carry out operations is distributed between agents and artefacts. We identify the central themes from the theory of DSA which are useful in describing modern day complex socio-technical systems. Further, based on the central themes, we propose guidelines for evaluating bridge teams involved in pilotage operations.

1 INTRODUCTION

Despite the introduction of automation onboard merchant ships, navigation remains primarily a team-dependent task. This is evident in the pilotage leg of navigation where the ship is jointly navigated by the bridge team along with the pilot. The successful outcome of pilotage operations depends upon effective performance of bridge members as a team. Bolstad et al. (2002) have defined team as a number of individuals with combined endeavor working towards a common goal. The bridge of a merchant ship can be viewed as a complex collaborative system as it is operated by a team of highly specialized individuals using various navigational equipment at their disposal and requires interactive communication (Sandhåland et al. 2015). Even though, the research on safety and training simulators have escalated in recent years (Kluge et al. 2014), accidents continue to happen and operators at sharp end have been attributed (the so called human error element) for those accidents (Grech et al. 2008). According to the report published by European maritime safety agency (EMSA) for the period 2011-14, a total of 9180 maritime incidents of varying severity were reported. In response, about 600 safety recommendations were issued, out of which safety of navigation constituted a substantial share (13%) only to be preceded by operational practice (43%) and human factors (17%) as the area of focus (EMSA, 2015). However, given the potential of casualties and damage to environment that can occur due to navigation – related accidents, the analysis of factors affecting bridge operations merit paramount consideration. The collision between passenger ship *MV St. Thomas Aquinas 1* and cargo ship *MV Sulpicio Express 7* in the Philippines which resulted in heavy casualties and subsequent damage to the environment as the result of accompanying oil spill serves as a stark reminder (NDRRMC, 2013).

As suggested by Kim & Nazir (2016) and Schröder-Hinrichs et al. (2012) in their separate analysis of *Sewol* and *Costa Concordia* disasters respectively that a combination of several human and organizational factors lead to the accidents. Consentient to above, the authors believe that attributing the whole culpability to the bridge team would be unwarranted. However, it is to be noted that the erroneous actions carried out by the bridge team can set off a chain of events that can potentiate the vulnerabilities to the system. The introduction of modern technologies in the bridge (most notably ECDIS) has added another dimension in the complexity of pilotage operations. Technological changes, while increasing information processing can have a detrimental effect on Situation Awareness (Grech & Horberry (2002), as cited in Grech et al. (2002), p.1721).

The concept of Situation Awareness (SA) which traces its origins from the military aviation domain (Endsley, 1995a) has also led to research in other domains and can be termed as critical consideration in collaborative system design and operation (Salmon et al. 2009). In their analyses of maritime accident for the period between 1987 and 2001, Grech et al. (2002) have stated that 71% of the human errors can be attributed to problems related to SA. There are many ways in which SA can be defined however, the most widely used definition is the one given by Endsley (1995a), where SA is termed as perception of information elements in the surrounding, comprehension of their meaning and projection of their future status. Taking a systemic view, Stanton et al. (2006) have proposed the theory of Distributed Situation Awareness (DSA) which they argue can better explain the technology mediated interactions and dynamic nature of SA within complex collaborative systems. DSA is defined as "activated knowledge for a specific task, at a specific time within a system" (Stanton et al. 2006, p.1291).

In this paper we compare some of the central themes related to the theory of DSA in the context of pilotage operations and argue that evaluation methods for bridge team performing pilotage operations in simulated or real scenario should have underpinning assumptions on theory of DSA.

2 PILOTAGE OPERATIONS IN MARITIME DOMAIN

Pilotage can be termed as one of the most complex and critical operation in the maritime domain (Darbra et al. 2007). The importance of piloting vessels with continuously increasing dimensions and hazardous cargoes in the vicinity of some of the biggest metropolitan areas in the world has been undermined in the research literature and by the industry (Van Erve & Bonnor, 2006). Even after ignoring the factors like culture, weather and geographical challenges, studies involving pilotage has received less attention in their basic form as well. Lappalainen et al. (2014) have pointed out that pilotage is studied very little internationally or otherwise and have argued for pilotage based on established "good practices" as deemed by the literature.

Bruno & Lützhöft (2009) have defined pilotage as the control of a complex system and theorized that combination of feedback and feedforward mechanism is used in the pilotage to build a construct and exercise control on the system. Although the composition of bridge team varies depending upon the type of vessel and other factors, it can be postulated that bridge team during pilotage effectively involves coordination between Captain, Pilot and Duty officer. The captain has the overall responsibility of the safe execution of operation and acts on the advice given to him by the pilot pertaining to specific information to be considered when maneuvering in the port. Pilot is an individual, usually a master mariner himself, who has the specific knowledge related to navigation and traffic regulations in the port of call. Duty officer is the junior navigation officer present in the bridge who usually assist the captain in navigation by performing associated secondary functions (such as monitoring the helm orders, cross-checking position etc.) and acts in a supportive capacity. Figure 1 describes the flow of information in the bridge during pilotage operation.

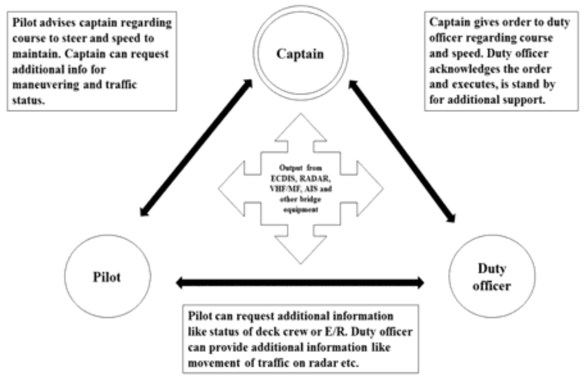

Figure 1. Information flow on bridge during pilotage operations.

The communication links and the interfaces the equipment have, effects how the team builds and maintain SA. The bridge team has a continuous exchange of information amongst each other and artefacts at their disposal. The execution of tasks is carried out by interaction and feedback received. The SA in this case can said to be distributed at system level, the team is acting as a joint cognitive system.

3 DISTRIBUTED SITUATION AWARENESS

The theory of DSA, originally proposed by Stanton et al. (2006) describes SA as an emergent property which is distributed across the agents and artefacts within a socio-technical system (Salmon et al. 2009, p.58). In other words, SA is to be analyzed at a systemic level in such settings. The methodology of DSA, as described by Stanton et al. (2006) can be summed into three main parts: (1) Elicitation of knowledge (2) Extraction of knowledge objects and (3) Representation of relation between knowledge objects and the phases where they are activated. Salmon et al. (2009, p.59) have stated that in collaborative systems, team members may be engaged in perception, comprehension and projection tasks separately, thus drawing an extension to Endsley (1995a) model for the SA to the context of collaborative system.

However, there are some unique positions also taken by the proponents of DSA theory. Notably the notion that SA at team level is compatible in nature. Salmon et al. (2010) theorize that the different team members due difference in goals, roles, schemas etc.

may have different view of situation and therefore rather than sharing what they know, the cohesiveness in the team is achieved by compatibility, or integrating the available information to their schemata and interpreting to their individual need.

Central to the DSA theory is the idea of transactional SA. Salmon et al. (2010) suggested that the SA is maintained in the system by the exchange of information between the agents or the transactions of SA. Teams with more transactions between members are found to perform better than teams with less transactions (Sorensen & Stanton, 2016). However, some communication between agents may be tacit in nature. One of the tenets proposed by Stanton et al. (2006) as the basis of DSA is that agents may communicate through non-verbal behavior, customs and practice.

Based on above, the theory of DSA can be summed up into the following main points which are relevant for collaborative settings: (1) The analysis is to be done at system level, taking all agents, artefacts and interaction between them into account. (2) The frequency of transactions is an important indication of team performance (3) Communication between agents may be tacit and (4) The SA of team is compatible in nature.

4 DSA IN PILOTAGE OPERATIONS

To date there has been little exploration of DSA in maritime domain. Of the applications presented in literature, Nazir et al. (2015) have described the key sub-systems and their interaction in maritime domain. Sandhåland et al. (2015), meanwhile, have provided empirical data about shipboard practices gathered from Platform Supply Vessels (PSVs) favoring a DSA perspective. Within the pilotage operations in maritime domain, there has been no previous application of DSA models or methods. Based on the central themes identified for the DSA theory in the previous section, pilotage appears to be an appropriate operation to adopt DSA perspective, however not without considering the limitations.

4.1 *SA is distributed across agents and artefacts*

During pilotage operation, the SA can be said to be distributed across agents and artefacts. The bridge team members are carrying out different activities and monitoring different aspects of the system and thus no one member of the team has the complete awareness or the "full picture". Further, some critical information, is being held by the bridge equipment. For the identification of the targets, the details are accessed through Automatic Identification System (AIS). This information is imperative in the navigation and collision avoidance during the pilotage and it is accessed by the bridge team members by viewing the AIS display or by an AIS overlay provided in the ECDIS. However, this theme does not address the issue, when the information is available to individuals but they may fail to perceive it due to various factors (Jones & Endsley (1996) as cited in Endsley (2015), p.26).

4.2 *SA transactions occur in bridge*

SA is maintained by continuous transactions between the agents. The bridge team members interact with each other, often in close-loop mode, for giving/following the navigation-related orders. The team also has to monitor or interact with Very High Frequency (VHF) radios in order to be aware of the traffic movements. However, an adequate number of transactions does not necessarily result in adequate level of SA as the relevancy and accuracy of communication should also be accounted.

4.3 *Tacit communication in bridge*

Non-verbal behaviors, customs and practices are carried out by the bridge team for tacit communication which may not be so apparent for non-native participant. This is in agreement with one of the tenets proposed for conceptual testing and identification of a system for the purpose of DSA analysis. Table 1 below provides an example.

Table 1. An example of tacit communication in the bridge during pilotage operation

Agent	Perception	Comprehension	Projection
Rate of in	Senses	Calculates the	Displays the rate
turn minute	change	rate of change	degree per
indicator	in heading		
Pilot	Reads ROT indicator	Determines counter-helm to be applied for steadying the ship	Gives the rudder order to Duty officer
Captain	Notices new rudder order given by the pilot	Determines the new heading to maintain course	Orders the new heading to pilot

4.4 *Bridge team has compatible SA*

In the case of maritime pilotage, the above argument can be given as the role of each bridge-team member is different in addition to the differences in experience, goals and hierarchy. The bridge team members including the pilot, act as a joint cognitive system in the execution of the tasks, where each member has their own sub-goals while the safe navigation from pilot point to the berth or vice-versa being the common goal for the team. One possible limitation in considering compatible aspect of SA in bridge is the physical proximity between the bridge team members during the operations. The team members are not separated geographically, therefore any role specific information or interface for the team members may not result in perceived advantage.

In Table 2, we present the pros and cons as discussed in aforementioned sections related to the applicability of DSA model for pilotage.

Table 2. Pros and Cons of DSA perspective for pilotage

Themes	Pros	Cons
System level analysis	Level of analysis includes bridge team and equipment.	Several factors such as cognitive processes also need to be considered
SA transactions	Indicates SA is maintained by transactions between bridge team. Accounts for dynamic nature of SA	Need to take into account the relevancy or accuracy of communication
Compatible SA	Takes into account difference in training, experience and roles. Bridge team members may require role -specific information presented to them	Relatively less physical separation in bridge. Compatible view may not give added advantage

5 DISCUSSIONS – BRIDGE TEAM WORK EVALUATION

With multiple agents working collaboratively in bridge to achieve a common goal and the argument that teams have cognitive properties, the evaluation of bridge team members should be based on measures that best capture their performance. As discussed above, the concept of DSA merits consideration when measuring performance of teams in collaborative settings. The methods which are adopted for measuring bridge team performance should therefore, have an underpinning on theory of DSA as described above. The following guidelines should be used when evaluating team work in pilotage operations:

5.1 *Mapping information elements and their usage*

Mapping of information elements have been found to be useful in team performance research as they reveal the underlying knowledge network (Marshall et al. 2015). Salmon et al. (2008) and Stanton et al. (2009) have proposed the use of propositional network methodology which describe the system SA as the network of information elements. The term "information elements" refers to concepts in assessing the DSA (Salmon et al. 2009, p. 63). The usage of information elements by bridge team members during the different stages in pilotage can give an indication of SA. Thus, SA can be measured dynamically and it would be possible to identify which members had the access to which subset of information elements. One possible limitation of this approach is that it is subjective in nature, therefore requires validation by comparing multiple sets of data (Salmon et al. 2009, p.71). Figure 2 provides an example of propositional network for pilotage operation. The information elements represented here is the knowledge used by agents and artefacts for the operation.

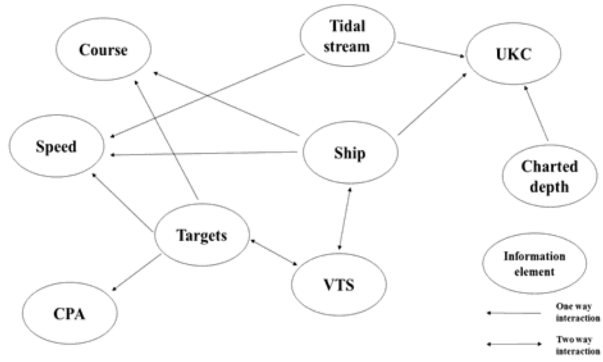

Figure 2. An example of propositional network for pilotage operations.

5.2 *Frequency of communication*

The frequency of communication is an important indicator of team performance. As demonstrated by Sorensen & Stanton (2016), the teams with more communication perform better. Therefore, the frequency of communication can be described as a measure for evaluating team performance. The use of frequency scale for team performance assessment is appropriate when quantity of occurrence for certain action is characterizing the performance of teams (Smith-Jentsch et al. 2013).

5.3 *Measuring interaction at various levels*

Bridge team members in pilotage operation have different levels of interactions. The team members have individual level of interaction as well as amongst team members. In this situation, the performance should be measured at multiple levels i.e. individual level and team level (Marshall et al. 2015). If all measures are taken at one level, it may be insufficient to detect deficiencies in team performance (Rosen et al. 2008).

6 CONCLUSION

In this paper, we have argued that theory of DSA can have implications on bridge team work. DSA of the bridge team members and the interactions amongst them are important factors to be considered during pilotage. Finally, based on the central themes identified from the DSA theory, we have proposed guidelines that can be considered when evaluating bridge team performance.

7 LIMITATIONS

The proposed application of framework and evaluation guidelines are theoretical in nature based on state of art knowledge. Further studies in the context of pilotage will contribute to the validity of guidelines proposed here.

8 FUTURE RESEARCH

We suggest that future research should be directed into modelling of DSA in pilotage operations by the use of propositional network methodology and exploring the relationship between frequency of communication between bridge team members and performance in laboratory settings. The authors are currently involved in designing an experiment for the purpose of modelling DSA in pilotage operations.

ACKNOWLEDGEMENTS

The authors of this paper would like to thank Ms. Raheleh Kari, graduate student at University College of Southeast Norway for her contributions.

REFERENCES

Bolstad, C. A., Riley, J. M., Jones, D. G., & Endsley, M. R. (2002). Using Goal Directed Task Analysis with Army Brigade Officer Teams. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 46(3), 472-476. doi:10.1177/154193120204600354

Bruno, K., & Lützhöft, M. (2009). Shore-based pilotage: pilot or autopilot? Piloting as a control problem. Journal of Navigation, 62(03), 427-437.

Darbra, R. M., Crawford, J. F. E., Haley, C. W., & Morrison, R. J. (2007). Safety culture and hazard risk perception of Australian and New Zealand maritime pilots. Marine Policy, 31(6),736-745. doi:http://dx.doi.org/10.1016/j.marpol.2007.02.004

EMSA. (2015) Annual Overview of Marine Casualities and Incidents. Retrieved from www.emsa.europa.eu/publications/technicalreports-studies-and-plans/.../23.html

Endsley, M. R. (1995a). Toward a theory of situation awareness in dynamic systems. Human Factors,37(1),32-64. doi:10.1518/001872095779049543

Endsley, M. R. (2015). Situation awareness misconceptions and misunderstandings. Journal of Cognitive Engineering and Decision Making, 9(1), 4-32.

Grech, M., & Horberry, T. (2002). Human error in maritime operations: situation awareness and accident reports. Paper presented at the 5th International Workshop on Human Error, Safety and Systems Development, Newcastle, Australia.

Grech, M., Horberry, T., & Koester, T. (2008). Human factors in the maritime domain. Boca Raton, USA: CRC Press.

Grech, M. R., Horberry, T., & Smith, A. (2002). Human Error in Maritime Operations: Analyses of Accident Reports Using the Leximancer Tool. Proceedings of the Human Factors and Ergonomics Society Annual Meeting,46(19),1718-1721. doi:10.1177/154193120204601906

Jones, D. G., & Endsley, M. R. (1996). Sources of situation awareness errors in aviation. Aviation, Space, and Environmental Medicine, 67(6), 507-512.

Kim, T.-e., & Nazir, S. (2016). Exploring marine accident causation: A case study. Occupational Safety and Hygiene IV, 369-373. Leiden, The Netherlands: CRC Press

Kluge, A., Nazir, S., & Manca, D. (2014). Advanced applications in process control and training needs of field and control room operators. IIE Transactions on Occupational Ergonomics and Human Factors, 2(3-4), 121-136.

Lappalainen, J., Kunnaala, V., & Tapaninen, U. (2014). Present pilotage practices in Finland. WMU journal of maritime affairs, 13(1), 7799.

Marshall, A., Bisbey, T., & Salas, E. (2015). Teamwork and Team performance measurement. In J. R. Wilson & S. Sharples (Eds.), Evaluation of human work (4th ed., pp. 773-789). Boca Raton, FL: CRC press.

Nazir, S., Carvalho, P. V. R., Øvergård, K. I., Gomes, J. O., Vidal, M. C. R., & Manca, D. (2015). Distributed Situation Awareness in Nuclear, Chemical, and Maritime Domains. Chemical Engineering Transactions, 43, 1993 1998.

NDRRMC. (2013). Sitrep 12 re Collision between MV Sulpicio Express 7 & MV St. Thomas Aquinas 1. Retrieved from http://www.ndrrmc.gov.ph/attachments/article/2475/SitRep_No_12_re_Collision_Incident_between_MV_Sulpicio_and_MV_St_Tomas_Aquinas_as_of_29AUG2013.pdf

Rosen, M. A., Salas, E., Wilson, K. A., King, H. B., Salisbury, M., Augenstein, J. S., . . . Birnbach, D. J. (2008). Measuring team performance in simulation-based training: adopting best practices for healthcare. Simulation in Healthcare, 3(1), 33-41.

Salmon, P. M., Stanton, N. A., Walker, G. H., Baber, C., Jenkins, D. P., McMaster, R., & Young, M. S. (2008). What really is going on? Review of situation awareness models for individuals and teams. Theoretical Issues in Ergonomics Science, 9(4), 297-323.

Salmon, P. M., Stanton, N. A., Walker, G. H., & Jenkins, D. P. (2009). Distributed situation awareness Theory, Measurement and Application to Teamwork. Surrey, UK: Ashgate.

Salmon, P. M., Stanton, N. A., Walker, G. H., Jenkins, D. P., & Rafferty, L. (2010). Is it really better to share? Distributed situation awareness and its implications for collaborative system design. Theoretical Issues in Ergonomics Science, 11(1-2), 58-83.

Sandhåland, H., Oltedal, H. A., Hystad, S. W., & Eid, J. (2015). Distributed situation awareness in complex collaborative systems: A field study of bridge operations on platform supply vessels. Journal of Occupational and Organizational Psychology, 88(2), 273-294. doi:10.1111/joop.12111

Schröder-Hinrichs, J.-U., Hollnagel, E., & Baldauf, M. (2012). From Titanic to Costa Concordia—a century of lessons not learned. WMU journal of maritime affairs, 11(2), 151-167. doi:10.1007/s13437-012-0032-3

Smith-Jentsch, K. A., Sierra, M. J., & Weise, C. W. (2013). How, when, and why you should measure team performance. In E. Salas, S. Tannenbaum, D. Cohen, & G. Latham (Eds.), Developing and enhancing teamwork in organizations (pp. 552-580). Hoboken, NJ: Jossey-Bass.

Sorensen, L. J., & Stanton, N. A. (2016). Keeping it together: The role of transactional situation awareness in team performance. International Journal of Industrial Ergonomics, 53, 267-273.

Stanton, N. A., Salmon, P. M., Walker, G. H., & Jenkins, D. (2009). Genotype and phenotype schemata and their role in distributed situation awareness in collaborative systems. Theoretical Issues in Ergonomics Science, 10(1), 43-68.

Stanton, N. A., Stewart, R., Harris, D., Houghton, R. J., Baber, C., McMaster, R., Young, M. S. (2006). Distributed situation awareness in dynamic systems: theoretical development and application of an ergonomics methodology. Ergonomics, 49(12-13), 12881311.

Van Erve, P., & Bonnor, N. (2006). Can the Shipping-Aviation Analogy be used as an Argument to decrease the need for Maritime Pilotage? Journal of Navigation, 59(02), 359-363.