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Shared Mental Models of Challenging Maritime Situations: Comparisons of Ship and Shore Personnel in the Straits of Malacca and Singapore

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ABSTRACT: Shared mental models, measured as similar perceptions and understandings of the components of a work task or an operative environment, is a key characteristic for high performing teams. Identifying and addressing differences in mental models may help enhance teamwork, and can serve as a frame for the improvement of human-centered information and communication systems. This paper has been written as part of the SESAME Straits project, a testbed within the e-Navigation framework. It examines similarities and differences in mental models between Deck Officers working aboard ships and Vessel Traffic Service Officers working ashore. Data was compared the participants´ perception of 12 challenging traffic situations in the Straits of Malacca and Singapore. A total of 189 respondents participated by means of an electronic survey. Findings show that Deck and Vessel Traffic Officers do have a large degree of shared mental models, but that there also are significant differences. In particular, there are large ship-shore differences in perceptions of the impact on local ship traffic on safety and efficiency. The second and third situation of large difference was delayed or reduced availability of port services, and challenging weather conditions. Implications are that future development of ship-shore collaborative systems should specifically explore and address the issue of local ship traffic, and to find ways to integrate information about availability and timing of port services and of difficult weather situations.

1 INTRODUCTION

Recent advances in information technology and computer power have the potential to further strengthen the quality of navigation and ship-shore collaboration (see for example Ward, Alexander & Greenslade 2009; Weintrit 2011; Kim, Jeong & Park 2013; Su, Chang & Cheng 2012; Bukhari, Tusseyeva & Kim 2013). However, new and advanced technology may also introduce new problems, such as information overload (Eppler & Mengis 2002, Jackson & Farzaneh 2012), and user interface complexity (Lützhöft & Dekker, 2002; Lützhöft & Lundh, 2008). In acknowledgement of these challenges, the International Maritime Organization (IMO) is now heading the e-Navigation initiative, promoting that new developments should be user centered and thus reflect actual operational needs and the limitations of human capabilities (Patraiko & Weintrit, 2010, ISO 9241). In this perspective, the task for further improving ship-shore cooperation is clearly not to simply introduce more functionality and information, but to make sure that specific user needs are identified and addressed.

A holistic approach to the future of ship-shore cooperation has been proposed by Van Westrenen and Praetorius (2014), based on the principle of distributed vs centralized control. They postulate that "when resources become insufficient (*e.g.* not enough sailing space), the traffic needs an organizing mechanism", that should promote increased ship-to ship and ship-to-shore communication, sharing of plans and closer cooperation. They further argue that the Vessel Traffic Service (VTS) does facilitate this to some degree today, but in an incomplete and unsystematic manner, and that the VTS and vessels need to be further improved in order to harvest the benefits of new technology. Mansson, Lutzhoft, and Brooks (2016) argue for a need for more research on the organizational part of the system, recommending a distributed team perspective.

One key factor for successful ship-shore team work is found to be the ability of VTS Officers to perceive and understand the navigational challenges in the same manner as the Deck Officers (Praetorius, Westrenen, Michell & Hollnagel, 2012; Praetorius, Bruno & Lützhöft, 2010; Van Westrenen & Praetorius, 2014; Praetorius & Lützhöft, 2012; Porathe & Brödje, 2015).

Thus, in order to harvest the benefits of new communication technology into systems that provide more useful information and functionality supporting ship-shore teamwork, more knowledge about the actual similarities and differences in perceptions between Deck and VTS Officers is needed. This paper presents findings from a survey with 189 respondents related to ship traffic in the Straits of Malacca and Singapore, undertaken as part of the SESAME Straits project.

2 MENTAL MODELS IN TEAMS

In their comprehensive review of teamwork research, Salas, Sims and Shawn Burke (2005) extract five core components which they name team leadership, mutual performance monitoring, backup behavior, adaptability, and team orientation. With respect to ship-shore cooperation, these five components appear to have already been established by formal rule and regulations (Van Westrenen and Praetorius, 2014). In addition, Salas *et al.* (2005) also identify three supporting coordinating mechanisms labelled closed-loop communication, mutual trust, and shared mental models, which they found to largely influence the degree of team success and performance.

As argued by van Westrenen and Praetorius (2014), while not directly affecting cooperative rules and regulations, an improved ship-shore planning system requires ability and willingness to adjust when plans are conflict with each other, *i.e.* to support cooperative behaviour and mutual adjustment. This is in line with Cannon-Bowers, Tannenbaum, Salas and Volpe (1995), stating that team members need to anticipate each other's needs, and that the shared mental model represents their common understanding of the environment, as well as the expected performance.

The reviewed literature indicates that ship and shore personnel have at least partially shared mental models, largely due to their background and training, but radio communication is also emphasized as an important contributor. However, the working environment and responsibilities at a VTS do differ quite a bit from those aboard a ship's bridge. The VTS Officer sits in a stationary control room where large computer screens are the main source of visual information displays. Deck Officers are aboard a moving vessel, affected by the changing forces of nature. He/she is also aided by computerized information in navigation, but is to give the highest priority to direct visual information and bearings from the surrounding environment (Witherby, 2016). We have known for a long time that these differences in available information from the environment can affect human behaviour – both on a theoretical level (Gibson, 1979) and from empirical research in the maritime domain (Øvergård, Bjørkli, Hoff & Dahlman, 2005) as well as in process industry (Nazir, Sorensen, Øvergård & Manca, 2015).

Thus, a closer study of similarities and differences in mental models between sea and shore personnel seems appropriate in order to address specific issues for improvement, rather than simply feeding more information onto the operators.

3 SHIP TRAFFIC MANAGEMENT IN THE STRAITS OF MALACCA AND SINGAPORE

The Straits of Malacca and Singapore (SOMS) is one of the busiest and complex waterways in the world (Qu & Meng, 2012), and thus a highly relevant area for the exploration of ship-shore mental models. Besides VTS services, various private companies offer marine advisor services (*i.e.* deep sea pilots) to aid ship sailing the international waters of the SOMS (Witherby, 2016). Within the Singapore harbour area, official pilot services are required and provided by the Maritime Port Authority of Singapore.

Due to political interest for the improvement of ship traffic safety and efficiency, there is a record of previous ship traffic projects in the region such as the Maritime Highway (Marlow & Gardner 2006, Dahalan, Zainol & Ting 2013), and also in the ongoing SESAME Straits project (http://straits-stms.com/, 2016), where the goal is to contribute to improvement in four aspects of ship traffic management (STM). These four aspects are described in table 1.

Table 1. Aspects and goals of Ship Traffic Management.

No.	STM aspect	STM goal
1	Safety	Increase safety, reduce chances for incidents/accidents
2	Delays (in time)	Increase efficiency, reduce chances for delays
3	Fuel consumption	Reduce cost and emissions
4	Information provision	Provide more information that is of real value for mariners, and also avoid providing unnecessary information (overload/clutter)

4 RESEARCH PROBLEM

We want to identify the extent of differences in sea- and shore-based personnel´s perceptions of the various aspects of ship traffic in the SOMS.

Differences in perceptions would be indicative of the differences in the focus the operators will have on different situations. Similar understanding of events increases the quality of collaboration and communication (Bruno & Lützhöft, 2005), and the lack thereof can create collaboration problems – especially for crew that are at different locations (Nazir et al., 2015).

In order to know how to support the development of increased ship-shore collaboration, we address the following research problem: *Identify any significant differences in the mental models of Deck and VTS Officers regarding challenging traffic situations in the SOMS".*

5 METHOD

5.1 *Research Design*

The research design is questionnaire-based and between-group, with quasi-experimental approach (due to the impossibility of assigning persons to jobs). Independent variables are group membership (Land-based or Ship-based), while the dependent variables are the relatedness of the described concepts (ref. table 1 and 2), constituting their mental models of the ship traffic situations.

5.2 *Sampling method*

Due to practical limitations, we applied a nonprobability, or convenience, sampling method. The survey was distributed to the VTS personnel and pilots at the Port of Singapore, as well as one company providing the services of marine supervisors. Deck Officers sailing the SOMS were reached with the help of members of relevant organizations and companies participating in the SESAME Straits project consortium.

5.3 *Participants*

Participating in this study we had the Ship-based personnel group, consisting of ship masters/navigational officers (N = 121, mean times through SOMS during the last five years = 19), and also marine advisors/pilots (N = 28, average years of experience = 8.5 and 13.8 respectively). The Land-based personnel group consisted of VTS Officers (N=48) and VTS Supervisors (N=20) at the Port of Singapore.

5.4 *Questionnaire development*

A review of the SOMS passage planning guide (Witherby, 2016) – in combination with input from domain experts in the SESAME project consortium – resulted in identification and definition of 12 challenging traffic situations (see Table 2 below).

Table 2. Traffic situations presented in the survey. NOTE: Situation 01 and 03 was removed in the survey for pilots/marine advisors, as the expert group did not deem these situations relevant for them.

No	Challenging traffic situation	Specification
01	Local fishing activities	Fishing vessels operating in the fairway Occurrence of drift nets and makeshift buoys in the fairway
02	Local ship traffic:	Service vessels and ferries crossing the fairway/lane
03	Changing fairway/lane constraints:	Changes in traffic separation zone and lane width Changes in fairway depth
04	Impact of deep draught vessels and VLCCs on traffic flow:	Giving VLCCs and other deep draught vessels required special attention Deep draught vessels that change speed or position in fairway / routes due to water depth constraints VLCCs crossing the fairway inbound/outbound Shell SBM in Singapore
05	Delays or reduced availability of: port services	Tugs and pilots, berths and terminals
06	Complex fairway traffic dynamics:	Ships ahead reducing speed and stopping in order to pick up for pilot/advisor Ships entering, leaving fairway/lanes (including crossing opposite lanes) Ships overtaking other traffic High traffic density at narrow sections or sharp turning points
07	Inappropriate behavior of other ships:	Ships changing course or speed with little regard to other traffic Ships not following rules and TSS regulations Ships not steaming at safe speed Ships impeding the safe passage of deep draft vessels
08	Communication challenges with ships:	Ships not responding to VHF calls, or only speaking local language Rouge or "unidentified" vessels Ships attempting to use VHF in collision avoidance instead of complying with ROR/COLREGS
09	Ship movement in anchorage areas:	Ships moving with small margins to other ships, and/or misjudge the impact of currents, wind and other influencing factors
10	Vessels that could hamper other vessels movements:	Restricted in ability to maneuver Not under command Vessel engaged in long-tow
11	Navigation aids problems:	Unlit buoy/beacon Displaced buoy
12	Challenging weather conditions:	Restricted visibility due to haze or squall/thunderstorm Strong or unexpected winds/currents

Based on these 12 challenging situations, a questionnaire was constructed based on an adaption of the mental model measurement technique called paired ratings. According to Ross and Allen (2012), paired ratings measurement is done by presenting participants with a matrix, where different central concepts are listed along the top and side, and then asking them to assessment the relatedness between them by providing scores on a numerical scale. The first set of concepts used for our study was questions relating to safety, delays, fuel consumption and information, according to table 1. The second set of concepts was the 12 challenging traffic situations described in table 2.

5.5 *Measuring relatedness by survey questions regarding STMS goals*

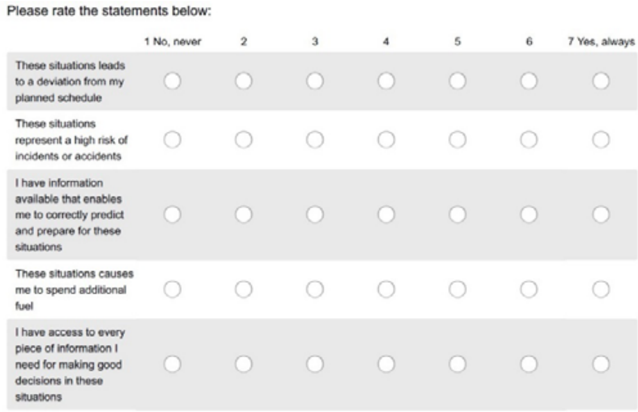
In order to identify relatedness between the ship traffic management goals and the traffic situations, respondents were presented with each traffic situation, followed by a rating scale containing the four traffic management aspects. We intended to address two different aspects about information availability (prediction in advance vs. handing a current situation). Thus, two question were made for this purpose (3 and 5), resulting in a total of five questions (see Figure 1 for all five questions).

5.6 *Statistical Analyses*

The IBM Statistical Package for Social Sciences (SPSS) version 23 was used for statistical analyses. A total of 4 MANOVA analyses (one for each of the main areas "Safety", "Delays", "Fuel Consumption" and "Information") was used to control for the family-wise error rate when investigating the presence of differences between shore based and sea based personnel on the impact of the 12 situations.

6 RESULTS

The multivariate models indicated that there were significant differences between land-based and Ship-based personnel on all four main areas; Delays (Wilks´ Lambda = 0.646, $F_{(12,\ 151)} = 6.90$, $p < 0.00001$; η_p^2=.354), Safety (Wilks´ Lambda = 0.751, $F_{(12,\ 151)} = 4.161$, $p < 0.00002$; η_p^2=.249), Fuel consumption (Wilks´ Lambda = 0.794, $F_{(12,\ 151)} = 3.259$, $p = 0.0003$; η_p^2=.206), and Information (Wilks´ Lambda = 0.706, $F_{(12,\ 151)} = 5.233$, $p < 0.00001$; η_p^2=.294). Because of this we did Bonferroni corrected pairwise comparisons of Land- and Ship-based personnel for all 12 situations for Delays, Safety, Fuel Consumption and Information. Adding the standardized mean differences for each of the four STMS goals provides a summary indicator of similarities and differences in the mental models of sea and shore personnel with respect to the various traffic situations. Table 3 shows the effect sizes measured in Cohen´s *d* (Cohen, 1988) for ship traffic delays, safety, fuel, information as well as the summed Cohen´s *d*.


Please rate the statements below:

	1 No, never	2	3	4	5	6	7 Yes, always
These situations leads to a deviation from my planned schedule	○	○	○	○	○	○	○
These situations represent a high risk of incidents or accidents	○	○	○	○	○	○	○
I have information available that enables me to correctly predict and prepare for these situations	○	○	○	○	○	○	○
These situations causes me to spend additional fuel	○	○	○	○	○	○	○
I have access to every piece of information I need for making good decisions in these situations	○	○	○	○	○	○	○

Figure 1. The seven point Likert rating scale applied for each traffic situation, spanning from "No, never" to "Yes, always". NOTE: In the survey for Land-based (VTS) the wording of the first question was modified to "These situations lead to ship traffic delays", and the last question was changed to "I have access to every piece of information I need for making correct assessment of these situations". This was due to the difference in the role of Land vs Ship-based personnel. With regards to questions 3 and 5, the average Pearson correlation across all situations was r = .768, the smallest correlation was r = .647 (for local ship traffic situation) and the largest correlation was r = .859 (for complex fairway traffic dynamics). Thus, we chose to combine these two questions as they both measured the information construct and were highly correlated.

7 DISCUSSION

Knowing about similarities and differences in shared mental models can help to improve team performance. Thus, we have gathered data about mental models from Sea and Land-based personnel in the Straits of Malacca and Singapore. 12 challenging traffic situations and 4 main ship traffic management goals were identified, and combined in an electronic survey based on the concept of paired ratings. Data were analyzed using statistical methods.

Our findings show that ship and shore personnel to a large extent have shared mental models of various traffic situations in terms of their impact on safety, delays and fuel consumption. However, there are also statistically significant differences.

When summarizing the standardized differences across all situations, local ship traffic (summed d_s=2.13) clearly stand out as a situation where Ship-based personnel perceive a lot higher impact on both delays (d_s=0.991) and safety (d_s=0.621) than Shore-based. Another significant and related difference is local fishing activities, where Ship-based score higher (d_s=0.723) than the Shore-based personnel. So, are Ship-based personnel overestimating the impact of these situations, or do the Land-based underestimate them? Literature is highly limited on this issue, but a study using risk modelling of ship traffic in the Strait of Istanbul (Ulusçu, Özbaş, Altıok, & Or, 2009), concludes that interaction between local traffic and transit traffic appears to be the most significant contributor to increases in risk. This provides support to the mental model of Ship-based personnel, *i.e.* that local ship traffic actually is a factor of large impact.

Table 3. Summary table of standardized differences between Land- and Ship-based personnel. NOTE: Table show standardized differences between the two groups (as measured in Cohen´s d_s), showing which group scored higher (grey = Ship-based score higher, white = Land-based score higher). Significant differences are marked in **bold**. d_s = Cohen´s delta with weighted and pooled standard deviations. Summed d_s are calculated by adding the four d_s´s for each situation. 'Delays' = Ship traffic delays, 'Fuel' = Fuel Consumption, 'Info.' = information, 'Sum d_s' = the sum of the four sample effect sizes. The larger the summed d_s the larger the differences between shore and ship personnel.

Situations	Delays	Safety	Fuel	Info.	Sum d_s	Rank
01 Local fishing activities	0.036	0.289	0.043	**0.723**	1.091	5
02 Local ship traffic	**0.991**	**0.671**	**0.374**	0.094	2.130	1
03 Changing fairway / lane constraints	0.057	0.129	0.232	0.258	0.676	10
04 Impact of deep draught vessels/VLCCs on traffic flow	0.126	0.037	0.165	0.063	0.391	12
05 Delayed / reduced availability of port services	**0.667**	0.228	0.079	0.308	1.282	2
06 Complex fairway traffic dynamics	0.102	0.196	0.006	0.112	0.416	11
07 Inappropriate behaviour of ships	0.284	0.202	**0.345**	**0.344**	1.175	4
08 Communication challenges with ships	0.282	0.303	**0.343**	0.006	0.934	7
09 Ship movement in anchorage areas	0.246	**0.349**	0.227	0.101	0.923	8
10 Vessels that could hamper movement of other vessels	0.176	0.185	**0.340**	0.211	0.912	9
11 Navigation aids problems	0.031	**0.323**	0.313	**0.356**	1.023	6
12 Challenging weather conditions	**0.495**	0.140	**0.440**	0.105	1.180	3

Another major difference in ship-shore mental models is related to *delayed / reduced availability of port services*. Shore-based personnel perceive this to have a lot higher impact (d_s=0.667) than does Ship-based personnel, and totally this situation ranks as second in terms of the total differences score (summed d_s =1.282). VTS has traditionally focused on vessel safety, not on efficiency, but these issues are of course interrelated - delays may produce high traffic density, which in turn affects safety. Some explanation of the mental model differences can be found in the recent study by Mansson *et al.* (2016), based on interviews of 24 Australian VTS officers. Here, one finding is that VTS officers are involved in issues related to port operations on the expense of core vessel traffic services, and that ship and shore personnel do not always base interpretations of the traffic situation on the same information. This support our findings on mental model differences also in the SOMS, and that the issue of ship-shore information sharing related to port services needs to be addressed in more detail.

8 CONCLUSION

Our study has identified that Ship and Land-based (VTS) officers have both similarities and differences in their mental models of traffic situations in the SOMS. The largest differences are related to the impact of local ship traffic, but significant differences are also found related to delays/reduced availability of port services, challenging weather conditions and inappropriate behaviour of ships. These four areas should be addressed specifically in the future development of collaborative technology systems for Ship and Shore personnel in the SOMS.

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