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Goal-Directed Task Analysis for Situation Awareness Requirements During Ship Docking in Compulsory Pilotage Area

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Abstract. In this paper we present the results from a Goal Directed Task Analysis (GDTA), a variant of cognitive task analysis techniques, to extract the operator's situation awareness requirements. This analysis is done with 8 pilots from the Mid Saint-Laurence Pilots Corporation (CPSLC) on a ship docking scenario in a compulsory pilotage area. These findings are used to develop a tool to measure the pilot's situation awareness during the maneuver using SAGAT questionnaire.

Keywords: Situation awareness, SAGAT, GDTA, pilotage, ship, marine navigation, docking.

1 Introduction

Marine navigation is a cognitively demanding task that requires the pilot to anticipate maneuvers long in advance, as the ship can take up to 30 minutes to come to a full stop due to its inertia. The pilot's situation awareness (SA) of the ship's surroundings and upcoming maneuver – or lack thereof – has been identified as a major factor in maritime accidents, but to this day only few studies have identified SA requirements for ship navigation and even fewer studies proposed a reliable tool to measure it [1], [2]. Moreover, there exist no study on pilot's SA in compulsory pilotage area, where the bridge authority is put under the responsibility of an expert pilot to maneuver in challenging seas, such as the Saint-Lawrence river in Qc, Canada.

In this study, we conducted a goal-directed task analysis (GDTA) during docking to identify the SA requirements and strategies adopted by pilots in a compulsory pilotage area. The article is organized as follows. Section 2 reviews previous works on situation awareness on ship pilotage. Section 3 presents the docking scenario and the interviewing methods used for data collection and section 4 presents the main situation awareness requirements found using GDTA. Section 5 puts the results into perspective and offers direction for future works.

2 Previous work

2.1 Situation Awareness

SA is defined as a person's perception of the elements in the environment within a volume of space and time, the understanding of their meaning, and the projection of their status in the near future [3].

This definition is based on a three-nested-level model developed by Endsley [3]. Level 1 consists of perceiving and attending the status and dynamics of element in the environment and is o fundamental in achieving SA. Level 2 is the comprehension of the perceived information. This phase involves integrating all cues collected in level 1 to determine their operational significance in view of pilot's goals. Level 3 is the highest in term of cognitive effort since it requires anticipating near future events based on the information collected from level 1 and 2.

Amongst the various cognitive task analysis methods, GDTA is a reliable method to extract SA requirements [4]. Rather than studying the pilot's task as with common task analysis methods (i.e., what the pilot does), GDTA focuses on the pilot's goals, decisions, and information requirements to fulfill the goals at the three levels of SA.

2.2 Ship pilotage

So far, the SA research in the maritime navigation domain is in an early exploratory stage. For example, Okazaki and colleagues [5] proposed the Situation Awareness Global technique (SAGAT) as a method for evaluating the performance of apprentice pilots. To this end, he considered a dense traffic scenario and the key variable was to evaluate the pilots' recognition of the surrounding vessel during a crossing manoeuvre. Results showed the importance of integrating SAGAT technique in pilots' training programs. However, the research has tended to focus on one information to measure the SA (the recognition rate of crossing ships).

Chauvin and colleagues [1] measured the SA of officer-in-training having less than 2 year of sea time using goal-directed probes with 11 SA requirements in a crossing scenario in open sea on a ship simulator. Participants were exposed to a challenging interaction situation in which they need to make a decision among various options. The study demonstrates that perception of the elements of the environment is not a significant factor in the decision-making process. Interpretation of the rules and anticipation of the other vessel's intention seemed to have a higher priority in the decision-making process. Both of studies [1] and [5] are putting more emphasis on the impact of a poor recognition of the key elements in the decision making process. However, it's not clear whether the findings generalize to the work of more experienced pilots. Sharma and colleagues [2], who qualified their study as exploratory given the novelty of research in the maritime domain, conducted a GDTA analysis with 7 experienced officers during pilotage phase in open sea and presented SA information requirements at all three levels. However, the docking maneuver was not analyzed, neither was the context of compulsory pilotage.

2.3 Compulsory pilotage

Compulsory pilotage areas are challenging navigation regions where incoming ships are required to be boarded and conducted by a marine pilot to its port of call. Marine pilots are highly trained officers who are intimately familiar with the coastlines, inland waters, shoals and ports of the pilotage area in which they are licensed. The bridge authority is put under the pilot's responsibility whose role is equally important to the captain.

The Saint-Lawrence river is one of the four compulsory pilotage areas in Canada spanning over 500 km of navigable water. It is administered by the Laurentian Pilotage Authority and licenses pilots are membered of one of two professional corporations: Mid Saint-Lawrence Pilots Corporation and Lower Saint-Lawrence Pilots Corporation.

3 Method

We conducted a GDTA study during docking at Trois-Rivières port, wharf 16 to collect the pilot's SA information requirements at all three levels.

3.1 Participants

8 pilots from the Mid Saint-Lawrence Pilots Corporation (*Corporation des Pilotes du Saint-Laurent Central, CPSLC*) took part in the study, with an average experience of 13.9 years of pilotage (std 8.3). They all had class-A pilotage license (ship over 210 m in length). The study received the approval of Polytechnique Montréal Ethics Research Board (CER-1920-05-D).

3.2 Scenario

The scenario used for the analysis is the docking at Trois-Rivières port, wharf 16. This docking is particularly challenging as the wharf is perpendicular to the river requiring 90 deg gyration to enter the dock and requires tugboats when the ship is longer than the wharf - **Fig. 1**.

An incident report that occurred in this section [6] summarizes the recommended docking maneuver as taught to all CPSLC apprentice pilots as follows:

1. ***The approach*** where the vessel should be brought from section 10 of the river until the entrance of the basin at an approximate distance of 3 vessel widths off the docks while maintaining a very low speed. At this point the pilot can decide whether to call for the help of tugs or wait for a closer point from the berthing zone ;
2. ***The use of anchor*** near section 11, to reduce the vessel's speed ;
3. ***The turn*** to be performed at 20 m from the corner of sections 16 and 17 with the help of tugs and the pilot's maneuvers (helm, engine propulsion) ;

4. ***Final position,*** decreasing gradually the vessel's speed and maintaining the bow on position with tugs assistance.

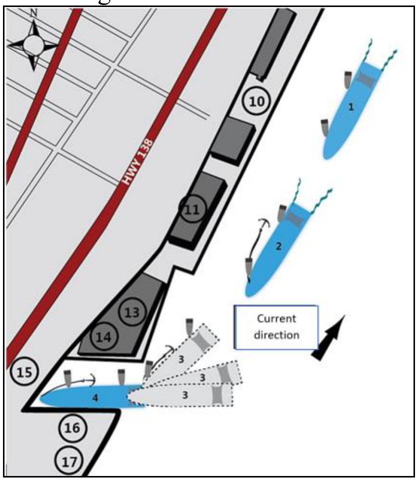

Fig. 1 Layout at wharf 16 and recommended berthing maneuver (from [6]).

3.3 Interviews

We conducted individual semi-structured interviews remotely using videoconference software to respect COVID-19 limitations. Interviews lasted from 60 min to 120 min and were recorded. Semi-structured interviews allowed us to extract a maximum of information from pilots and elicit their decision-making and cognitive processes during the maneuver. We used an interview guide that covered the main themes of SA requirements during a docking maneuver.

We constructed a preliminary interview guide and a hierarchical task analysis (HTA) of the docking with the help of a subject matter expert (SME) having over 20 years of experience. It was improved by making sure it covered themes from existing interview guides in literature [7], [2], [1]

The interview guide structure is illustrated in **Table 1**.

To support the pilot's recollection of the docking, we presented a video recording of the docking alongside navigation maps of wharf 16

Table 1 Interview guide structure

Phase	Themes	Comments and data collection
1	Briefing	Presenting the research, record verbal authorization
2	Presentation	Determining the pilot's profile
3	Summary of the maneuver	Extracting the main goals and the priorities
4	Questionnaire based on the recorded video	Participants describe the video and answers to the SA questionnaire
5	Preliminary GDTA presented	Adapt the GDTA according participants' perspective

3.4 Goal Directed Task Analysis (GDTA)

The interview transcripts were analyzed to identify the three main elements of the GDTA: the goal hierarchy, decisions about goal achievement, and information requirements. The distinction between these elements was made according to the definitions and criteria provided by Endsley and Jones [4]. Each goal was broken down into sub-goals, decisions, and ultimately requirements needed for its execution. The requirements of situational awareness have also been divided into three levels: perception (L1), comprehension (L2) and projection (L3). Similar goals and decisions were grouped together to avoid redundancy. During interviews, we also presented to participants the intermediary GDTA results to validate the analysis and the vocabulary used.

4 Results

For the situation awareness requirements, we found 8 main goals, 50 sub-goals and decisions, 80 level-1, 26 Level-2 and 10 level-3 information requirements. The main goals are presented in **Table 2**.

Table 2 Main goals of the docking maneuver at wharf 16

Overall main goal: Perform a safe docking mission in a reasonable delay
1. Prepare a safe and efficient docking plan
2. Obtain docking permission
3. Moor the tugs to the vessel
4. Maneuver the vessel on the established approach course
5. Perform a 180deg turn to position against the current
6. Make the turn in the basin according to the chosen approach
7. Enter the basin safely
8. Position the vessel at the dock

An extract of the information requirements is presented at **Table 3**.

Table 3 Extract of the information requirements

Extract of the information requirements from the sixth main goal
6. Make the turn in the basin based on the chosen approach
6.1. Determine the target location where the vessel begins its turn (at which position to start the vessel's gyration?)
Level 1 queries (L1)
6.1.1. Visual exploration
6.1.2. Electronic Chart Display and Information System (ECDIS)
6.1.3. Feedback from the officer at the bow of the vessel
6.2. Make the turn

Level 1 queries (L1)
6.2.1. Force and direction of flow
6.2.2. Wind force and direction
6.2.3. Vessel manoeuvrability
6.2.4. Current/desired vessel position
6.2.5. Speed over the current/desired background
6.2.6. Steering wheel
6.2.7. Engine power
Level 2 queries (L2)
6.2.7.1. Impact of external conditions on vessel drift and extent of turning: low, neutral, high
6.2.7.2. Impact of the vessel's performance and characteristics on the rate of turn: unfavorable, neutral, favorable
6.2.7.3. Impact of ground speed on the speed and magnitude of turning: unfavourable, neutral, favourable
6.2.7.4. Deviation between current and desired bottom speed
6.2.7.5. Control of engine power to correct the difference between the actual and desired ground speed: low, neutral, high
Level 3 queries (L3)
6.2.7.5.1. Expected speed over the ground at the turn
6.2.7.5.2. Expected position at the turn
6.2.7.5.3. Magnitude and speed of the expected gyration

For decision-making processes, we found that pilots use two strategies for docking when coming downstream. The traditional method implies to overpass the wharf and to complete a 180 deg gyration with the tugboat or the anchor to position the ship upstream, whereas in the non-traditional method the gyration is done downstream such that the ship is perpendicular to the river current when facing the dock and the tugboat is used to stop the ship from drifting. The decision criteria for the method selection are the ship dimension and weight – where larger and heavier ships would benefit from the non-traditional method as their gyration speed could be insufficient for such a swift turn –, wind speed and water speed – traditional method is preferred with increased speed –, traffic, draught, manoeuvrability, propeller rotation and ship propulsion. When coming from upstream, the pilot can stay close to the wharf and start the gyration nose-in when the tugboat is midway into the dock; or stay further away from the wharf with negligible ground speed such that the gyration is done almost stationary.

5 Discussion

The semi-structured interviews provided us with a rich and detailed insight into how decisions were made and allowed us to collect a large amount of relevant information in order to develop a highly comprehensive GDTA structure.

It is interesting to note that even though there are two different strategies that can be used for docking when coming downstream, the 8 main goals and the information requirements are similar among all pilots.

To this day, few studies have identified situation awareness requirements for ship navigation and even fewer studies proposed a reliable tool to measure it [1], [2]. In both of these studies, the participants were unexperienced [1] or experienced [2] navigators. Sharma and his colleagues [2] noted a significant dependency upon pilot to provide certain information that would have a major impact on the navigators' SA. Therefore, it seemed fundamental to have access to the pilot SA in order to fully understand the impact of SA and information requirements on the decision making. To the best of our knowledge, our study is the first to target a specific maneuver (i.e. docking) in compulsory pilotage area, where the bridge authority is put under the responsibility of an expert pilot to maneuver in challenging seas.

There are three limitations to our study. First, pilots relied on their retrospective memory and explicit knowledge to describe the maneuver and we were unable to make direct observations due to COVID-19 constraints. This could introduce a recollection bias of SA requirements related to implicit knowledge. Second, our participants pool was only composed of highly experienced pilots (i.e., range A) which could have an impact on the evaluation of the situation awareness. Pilots with more experience may not orient their attention to the same elements and in the same way of pilots with less experience. Finally, it is important to mention that even though communicational aspect is a major element of the situation awareness as mentioned before, we did not analyze shared situation awareness between bridge officers and the tugboat, as we focused on the pilot's situation awareness.

Altogether, the results of this study will allow us to develop the first Situation Awareness Global Assessment Technique (SAGAT) questionnaire evaluating the pilot's situation awareness for the maneuver of docking. The questionnaire will be validated on a ship simulator in future work.

6 Conclusion

In this study, we conducted a goal-oriented task analysis to extract the SA information requirements of marine pilots in compulsory pilotage area during the docking at Trois-Rivières port wharf 16. We identified 80 level-1, 26 Level-2 and 10 level-3 information requirements and found that pilots use two berthing strategies based on the environmental conditions. The SA information requirements found will be used to develop a SAGAT questionnaire to measure the pilot's SA during docking.

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