Navigating with safety in confined waterways: an explorative case study

Stella Parisi, Martin Fränzle

Department of Computing Science, Carl von Ossietzky University of Oldenburg

Abstract

This study explores how safe navigation is performed in restricted waterways in the North Sea from the point of view of maritime pilots. The purpose is to obtain and assess domain expert knowledge as part of an ongoing research project related to the analysis of critical factors that affect the bridge team build situation awareness while performing navigational tasks in such fairways. The study is based on the adaption of the knowledge elicitation technique of Applied Cognitive Task Analysis and ethnographic observations that were made during two sea voyages. The results indicate that the applied technique is promising for the intended analysis and can be used as input for the design of the next research phase. The findings have implications for studying safety critical tasks in the maritime domain.

1 Introduction

In the early morning of 5 April 2011, the Tanker Motor Vessel (TMV) ZAPADNYY and the TMV RHONESTERN, departed from the port of Bremen and proceeded on the River Weser in good visibility, calm weather and moderate traffic volume. They were navigated by their master with pilot advice and steered by a helmsman towards the North Sea. At around 8 o'clock, the stern of the RHONESTERN passed the superstructure of the ZAPADNYY in the area of the exit of the bend at Vegesack. A few minutes later, ZAPADNYY collided with the front end of a floating dock of a shipyard, which was firmly moored on the northern bank of the River Weser. During the overtaking, ZAPADNYY did not reduce speed for safety reasons but consented to participate in the overtaking maneuver and RHONESTERN was not aware of the difficult steerability of low motorized ZAPADNYY. None of the preventing actions taken by the crew caused the vessel to respond noticeably or helped to prevent her from straying towards the northern bank. The published accident report states that *"it is impossible to make a statement with sufficient certainty as to whether a decision to increase or reduce speed after the onset of a hydrodynamic effect in this single case under consideration, would in fact have had limited the impact of the accident"* (BSU, 2012).

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This incident illustrates some of the issues related to obtaining and maintaining Situation Awareness (SA). How can we know what are the critical information elements during a navigational operation that the bridge team should consider when making decisions? This paper presents the results of a case study related to maritime pilotage operations in the waterways of the German Bight region in the North Sea. The study is the initial part of an ongoing research project related to analyzing critical elements that affect the SA of the bridge team during such navigation operations. The goal is to get an insight into the everyday activity of navigating and maneuvering ships in confined fairways and to explore in context what elements pilots consider as critical. The results of this study will inform the further research steps and outline the challenges for the appropriation of the proposed methodology for analyzing SA in the described safety critical system.

2 Background

Human error is still the major reason for 62-85% of maritime accidents worldwide (Grech et al 2002, Baker & McCafferty 2005, European Maritime Safety Agency 2016). About 70% of these are the result of failed SA and assessment of the situation at hand (Hetherington et al., 2006). According to an analysis of a sample of over 500 accident reports, fatigue, workload and stress followed by errant mental models, data overload and attention tunneling are the most common causes that corrupt the SA of human operators in the maritime domain (Stratmann & Boll, 2016). SA is defined as "The perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1995). Many researchers have studied the past years this human factor construct in sea navigation, and the Manila amendments have addressed SA and decision making as key components of sound seamanship (Øvergård et al, 2015, Cordon et al, 2017). SA provides what is needed to enable planning, decision making and action selection. It is affected by environmental, personal, organizational and informational factors (Safahani & Tuttle, 2013). The combination of inertia and concepts that are not directly observable, such as hydrodynamic interactions or wind effects, differentiate the concept of SA in maritime compared to other domains (Westrenen & Praetorius, 2012).

Ship navigation is a high risk task that involves performing complex procedures and ensuring the safe passage of vessels into and out of port through channels, while making predictions about possible traffic developments (Chambers & Main, 2015). During the undertaking of a critical course alteration, the navigation of a ship close to the limits of its operating envelope can be a resource demanding and exacting task. These are generally the most difficult parts of a voyage, with small safety margins, complex manoeuvres, tidal waves, strong currents, and tight time schedules (Westrenen & Praetorius, 2014). The use of the ship bridge systems and the efficient communication of the available related information can significantly increase the safety of the operation (Wild, 2011). To achieve this, designers of such systems should identify and study the key factors that affect the navigation team build and maintain SA at the initial steps during the system development process.

3 Case study

When researchers aim for a successful design of a complex system intended for use in safety critical domains, they need to build a detailed, multi-faceted understanding of how the work is done, how users interact, how tools are used, what users need, what policies are in place and other related questions (Lazar et al, 2014). An explanatory case study was conducted to investigate in context how ships navigate with safety in the North Sea fairways from the point of view of the maritime pilot. The case study methodology was chosen because of its qualitative aspects, which are useful for describing and explaining the decision making activities of the pilots during their operations.

3.1 Interviews

Initially a literature review was performed in order to identify existing methods for eliciting expert knowledge, specifically in the maritime domain and similar command and control environments. Cognitive task analysis (CTA) techniques seemed to be more fitting to the research goals since they are used to illustrate the knowledge, thought processes and goal structures related to the task at hand and focus on deriving the cognitive elements related to decision making and judgements. The Applied Cognitive Task Analysis (ACTA) was selected. It is an interview based CTA technique that can allow analysts to extract the critical cognitive elements of a specific scenario (Stanton at al., 2013). ACTA has been successfully applied in the maritime domain in a case study with Vessel Traffic Service (VTS) operators, where a mid-fidelity simulation design was developed and included a combination of various knowledge eliciting techniques (Brodje et al, 2011). A trial run of the ACTA was realized to ensure the followed method will produce good results.

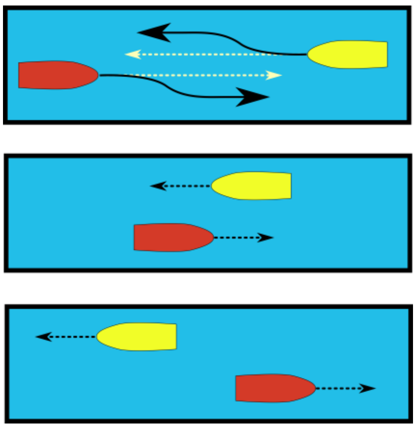

Figure 1: The scenario used in the interviews. Vessel A (red) and Vessel B (yellow) interact in a narrow channel.

1. *Procedure*: A simple low fidelity scenario was prepared in cooperation with mariners and human factors researchers for the trial run, based on typical maritime operations and on the

relevant International Regulations for Preventing Collisions at Sea. It involves two ships, vessel A and vessel B, that meet in a narrow channel, as seen in Figure 1. The scenario is an abstraction of the Weser incident and was preferred over the actual incident for the trial run of the interviews for time and complexity reasons. Two experienced mariners from a local pilot station were involved in the trial run. After conducting the first round of ACTA, the method was slightly refined to reflect better the thinking patterns of the interviewees. The ACTA findings and the scenario were discussed and evaluated with a former navy mariner and human factors expert. Both meetings were transcribed and extensive notes were taken during discussions that lasted on average about 1,5 hours each.

2. *Participants*: After establishing contact and a first meeting with one of the pilots at the station, two interviews were conducted separately on one day at the working place of the participants. The experts were given to fill in consent forms and data forms regarding their seafaring experience. The two pilots (from now on referred to as P1 and P2) are both on active duty. They both have 32 years total seagoing experience and 5 years as a master mariner. Their experience as pilots is 10 years for P1 and 15 years for P2. Both interviews were recorded and transcribed.

The ACTA techniques were adapted as described in (Stanton et al., 2013). First, a Task Diagram was made where the experts were asked to describe the navigational act into three to six sub-steps/subtasks and highlight the parts that are cognitively challenging. The second phase was the Knowledge Audit, where probes such as "*What are the major elements you have to know and keep track of?*" or "*Can you describe an instance when you spotted a deviation from the norm, or knew something was amiss?*" were used to guide the pilots to describe the use of expert knowledge for the task. The third step was the Simulation Interview and is concerned with eliciting information on how the pilot operates within the context of the scenario of Figure 1. The fourth step was to create with each pilot an initial concept map with the information elements that the experts believe to be critical during the studied task instead of a Cognitive Demands Table. Semi-structured questions such as "*What pieces of information led you to this situation assessment and these actions?*" and "*In what ways can the decision be difficult? What errors would an inexperienced person be likely to make in this situation?*" facilitated the discussion.

The main rule that applies in the scenario of Figure 1 is to "keep to the starboard side, passing on-coming traffic port-to-port". Both pilots separated the studied task, as it is depicted from top to bottom in Figure 1, into three major subtasks. For each of the subtasks, the pilots identified different concepts that they consider when they want to assess the situation. Some of the concepts are common in all subtasks, other emerge or become irrelevant when a subtask is over. This is in line with the argument by (Westrenen & Praetorius, 2012) that navigators focus on some elements depending on the desired goal and the chosen plan - not everything is important. Table 1 presents an overview of the subtasks and the related information elements.

Due to the limited number of participants and the pilot aspect of the ACTA application, results have to be considered as explorative. It can be argued that the scenario design has managed to keep close to the familiar task, in order to get a good understanding of the mental operations and judgements with the available resources. Both experts described the scenario as general but appropriate to obtain some broad knowledge on the activity of pilotage in confined waters.

They pointed out some constraints that need to apply, such as the type of ships used in the scenario, the location, traffic, weather conditions and the cargo. Without these constraints they could not offer answers, as this knowledge guides their strategical and tactical thinking in such scenarios. Their feedback is valuable in shaping a version of ACTA that can elicit knowledge effectively for a more critical scenario. It also notable that the consensus between the gathered data from the trial run is estimated at more than 80%, which is encouraging for the methodology design and indicates that the choice of this technique is fitting.

Subtask	**Elements**
Find the optimal passage position	Own Vessel (Speed, dimensions, characteristics, draft, tide, wind) Other Vessel (Speed, dimensions, characteristics, draft, tide, wind) Fairway (structures, depth, diameter, tide, condition) Maneuverability (Propeller type, engine power, Rudder) Traffic regulations (Vessel length >270, VTS is obligatory)
Monitor the safe passage	Own Vessel (Spatial form, speed) Other Vessel (Speed, spatial form) Hydrodynamic Interaction Ship-Ship (speed, distance) Hydrodynamic Interaction Ship-Shore (Distance from bank, maximum maneuvering speed, vessel speeds)
Return to a comfortable spot	Other traffic (speed up actions) Fairway status Own Vessel information Maneuvering abilities

Table 1: Overview of the subtasks for the studied scenario and the related concepts that support the pilots obtain and maintain situation awareness

3.2 Ethnographic Research

The second part of the case study was a field trip to observe the activities of a pilot and a bridge crew during an inbound and outbound voyage in the maritime traffic zones of Jade, German Bight and Bremerhaven - Weser in the North Sea. While we are aware that observing a trip in the Jade–Weser estuary and not in the Weser river could have a possible impact on empirical validity, this is the best we could currently achieve. The choices for the field trip locations were limited by the necessity of finding pilots that responded to our requests for cooperation.

Our approach was to shadow the pilot as he performed his tasks and ask questions whenever clarification was needed. The role of the researcher was open to all crew members and people involved. The purpose of the research was explained briefly to both ship crews and the consent forms were distributed and signed. Guided field notes, photos and video recordings were taken and there were open questions and discussions with the members of the crews and the pilot.

The field trip was realized in good weather conditions and without any critical incidents. Departure was from the naval base in Wilhelmshaven with a chemical tanker. The first voyage lasted 2 hours, then the group of the pilots and the researcher disembarked during sailing in the German Bight to a pilot vessel, a small and fast boat that transfers pilots from and to ships that ask for their services. The second leg of the trip with a cargo ship was inbound and lasted about 4 hours. Again, another pilot vessel transferred the group from the cargo ship to the Bremerhaven Pilot Station, which was the final destination. A voyage map can be seen in Figure 2.

Both ship crews followed the protocol during the procedures of the arrival, change and departure of the pilots and the researcher and were happy to assist with the research activities. A trainee pilot was in both trips and the main pilot was supervising his actions. The main pilot was acting as the key informant and the presence of the trainee pilot who was performing most of the pilot duties affected positively the collection of content and enabled rich discussions. The master was always in control in both ships and all pilots had advisory roles.

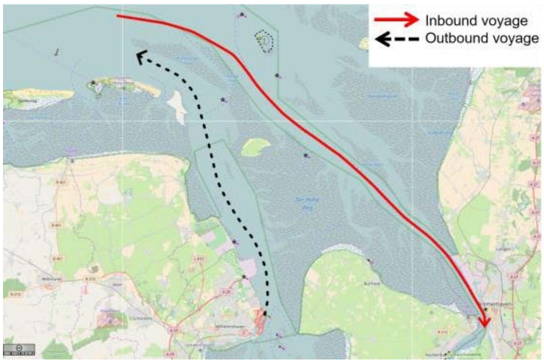

Figure 2: The area of the outbound voyage (black dotted line) with Katelina and the inbound voyage (red line) with EEMS Dundee in the Jade–Weser estuary. Map data © OpenStreetMap contributors.

During the second trip, the bridge team performed an overtaking maneuver while sailing in the German Bight fairway. At that point, the communication with the VTS operator intensified. A third vessel participated in the operation. Its role was to exit temporarily the fairway in a spot assigned by the VTS and enable the overtaking maneuver. The pilot explained that without this action by the third ship, the overtaking might not have been possible at all, because a possible meeting in the fairway later would be critical for both vessels. This incident highlights the role of the VTS in maritime traffic management, the resource management from the different ships and the culture of safe navigation in the fairways.

Communications with the VTS and the pilot station were in English and in German with the Ems VTS station and only in German with the Bremerhaven VTS station. Pilots claim it makes their jobs easier to get the information in only one language. Both crews made inquiries to the VTS operator and used the ship bridge communication instruments when unrecognized vessels were spotted. The pilot used less his portable pilot unit in the second vessel, which had a ship bridge system of recent technology. Autopilot was used at all times during the second voyage.

4 Discussion and Outlook

The use of participatory methods for design and modeling requires the involvement of experts in all stages, from early discussions aimed to understand critical aspects of an operation and user needs to active contribution in the end result via semi structured interview sessions and evaluation. The presented study has been an important first step to establish a rapport with the experts and to gain specialized knowledge and field experience that will allow the creation of a fitting navigational operation scenario for the subsequent research steps.

CTA methods can be time consuming and might need repetition if their analyzed data are not satisfactory and fitting, therefore it is recommended to pilot them with experts. Besides evaluating and refining the technique, adapting and applying ACTA with 2 maritime pilots offered some valuable initial data. It also indicated a more focused direction for creating an appropriate scenario with more graphical and operational details for the Simulation Interview. Another insightful indication is the number of experts that will be needed for the next round. Since the consensus between the answers of the 2 participants is more than 80%, 4-6 experts will be a good number of participants for the next phase of the project. The data analysis is a laborious process, therefore the presented technique needs revisions. To avoid research bias, different experts will be used as participants in the various stages of the research.

Qualitative expert knowledge can inform system design of the critical elements that impact SA in a pilot operation. The presented interviews with pilots, that hold one role in the bridge team, are not enough to lead to concrete conclusions on actual team SA. The interpretation and triangulation of the results requires caution, yet even those obtained in the trial run are promising for the appropriation of the method. Indicative groups of factors and preliminary critical elements have been outlined and the implied trade-off will guide a more effective application of the methodology. Such constraints can also be an opportunity for the system design, where an adaptable system tailored to the vessel needs can support better the decision making processes of the ship bridge team.

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