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Applied Cognitive Task Analysis (ACTA) of Marine Piloting in a Swedish Context

Cecilia Berlin[1] and Gesa Praetorius[2,3]

[1]Chalmers University of Technology, Department of Industrial and Materials Science, Division of Design and Human Factors, Hörsalsvägen 5, 41296 Göteborg, Sweden
[2]Swedish National Road and Transport Institute (VTI), Olaus Magnus väg 35, 581 95 Linköping, Sweden
[3]University of South-Eastern Norway, Faculty of Technology, Natural Sciences and Maritime Sciences, Post Office Box 4, 3199 Borre, Norway

ABSTRACT

Modern-day marine pilots are a competent and experienced workforce. They are highly skilled navigators that support the merchant fleet in transiting through challenging sea areas and rivers, as well as in the navigation in and out of ports. In this study, Applied Cognitive Task Analysis (ACTA) was used to pursue a deeper understanding of expertise and tacit or procedural knowledge that experts rely on and exhibit, mostly in safety-critical situations. ACTA is a structured interview method, which relies on three distinct phases: a task diagram, a knowledge audit and a simulation interview. In this article, results from the first two interview steps are presented to show the intricate complexity of pilotage and building blocks of expertise within marine pilotage. A total of eight experienced pilots from two different port areas in Sweden were interviewed. The results show that there are large differences in how pilotage is conducted in the two areas with regards to both tasks, knowledge and understanding of the service as such. Further, despite recognizing maneuvering as cognitively demanding, the pilots emphasized social skills and learning on the job as key elements of expertise. Conclusions drawn from the ACTA structure highlight the mentally and socially complex task that piloting is, and that the pilots use great discernment and acuity when processing verbal and non-verbal input, as well as physical human and vessel movements.

Keywords: Transportation, Maritime human factors, Maritime safety, Cognitive task analysis

INTRODUCTION

Marine pilotage is one of the foremost safety measures within maritime transportation. Marine pilotage is carried out by marine pilots in areas that are challenging to navigate in, such as port approaches or other sensitive sea areas (National Research Council, 1994). Pilots usually are experienced navigators who support the bridge-team of a vessel with their local expertise, and ease the communication flow between shore-based services such as Vessel Traffic Services (VTS), linesmen or tugboats (Darbra *et al.*, 2007). In Sweden, pilotage is offered by the Swedish Maritime Administration, which employs 230 marine pilots who offer nautical expertise and detailed knowledge of local circumstances to ensure a safe and expedient passage in Swedish waters (Swedish Maritime Administration, 2023).

While pilotage's and marine pilots' contribution to safety within maritime operations have been the focus of several studies throughout the past decades (e.g. Darbra *et al.*, 2007; Bruno and Lützhöft, 2009; Lahtinen *et al.*, 2020), only a limited number of studies have explored task design, knowledge and expertise in this domain (e.g. Orlandi, Brooks and Bowles, 2015; Butler, Read and Salmon, 2022). Therefore, little is known about what characterizes expertise and expert knowledge within this domain. This study contributes to the current body of knowledge by utilizing an adapted version of the Applied Cognitive Task Analysis (ACTA) framework (Militello et al., 1997; Militello and Hutton, 1998) to pursue a deeper understanding of what types of cognitive skills marine pilots rely on and exhibit when solving tasks, mostly in safety-critical situations. While, to the best of our knowledge, the application of ACTA within maritime settings has been rare so far (e.g. Brodje *et al.*, 2013), we believe that this structured approach can shed light on the complexity of everyday work and help to identify what characterizes expertise in marine pilotage. Within this article, we will focus only on the results obtained during stages one (task diagram) and two (knowledge audit) of the ACTA, due to limitations of paper length.

METHODOLOGY

This study has utilized an adapted version of the Applied Cognitive Task Analysis (ACTA) framework (Militello et al., 1997; Militello and Hutton, 1998) to explore everyday work of marine pilots. The ACTA method, developed in the late 1990s, can be described as a structured interview approach to identify cognitively demanding aspects of subject matter expert (SME) work within high-risk domains, such as firefighting or nursing. Rooted in the framework of naturalistic decision making (NDM), the method explores critical decisions and the use of information within dynamic environments with the aim to provide input into design and training.

ACTA is split into three data collection stages and one analytical stage. The first stage (task diagram) aims to establish an overall, high-level description of the task at hand; the second (knowledge audit) explores specific sub-tasks that the participant considers particularly mentally demanding, probing specific behaviors that are associated with expertise; the third stage (simulation interview) takes the participant through a simulated task (in this case, maneuvering to berth) in several steps, inquiring about what course of action they would take based on available information, and introducing situations that require intentional decision-making. This last data collection stage was supported in this study by mediating objects (i.e. visual aids such as printed sea charts, visual scene renderings from a simulator, and a model boat) to focus the discussion. The analysis of the structured interview is carried out in the fourth phase, called the Cognitive Demands Table (Militello et al., 1997).

After a pilot interview with an experienced maritime simulator instructor and former pilot was held, the authors found that purely using the ACTA guide as a linear manuscript for probing each stage and situation in turn was quite cumbersome, repetitive and time-consuming. The pilot interviewee also questioned the applicability of some particular probing questions, since most piloting assignments are not standardized in execution. To address these issues, the authors produced a complementary visual template in the form of a matrix on paper for the Knowledge Audit (Figure 1) and the Simulation Interview (Figure 2), to guide the interviewee towards discussing the cognitive skills in question, without requiring them to do so in a linear order.

A total of eight experienced marine pilots were individually interviewed (see Table 1). Four worked at a large industrial and commercial port on Sweden's west coast, area 1 (with container, ro-ro, car, passenger and oil and energy terminals), while the other four worked at a smaller commercial port on the east coast, area 2 (container and ro-ro terminals).

The interviews took between 52 minutes to 1 hour 42 minutes and were audio recorded for Phases 1, 2 and 3, while the third stage (the Simulation Interview) was also video-recorded in a way that only showed the participant's hands from above pointing to the visual mediating objects in the simulation sequence (Figure 3). The interviews were conducted in Swedish,

[Task at hand]		
Aspects of expertise	**a) Cues and strategies** (how is the need discovered?)	**b) Why difficult?** (what can make execution difficult?)
Past and Future (predicting the chain of events)		
Big picture		
Noticing cues and patterns		
Job smarts		
Opportunities/ Improvising		
Self-monitoring		

Figure 1: Visual matrix of the knowledge audit stage (translated from Swedish) used as a mediating object in this study.

Maneuvering to berth				
Steps (events where evaluation or decision-making occurs)	**What do you do?** (Actions)	**What is your judgment of the situation?**	**What clues do you use?**	**Possible mistakes for a less experienced pilot?**

Figure 2: Visual matrix of the simulation interview stage (translated from Swedish) used as a mediating object in this study.

Table 1. Sample information of interviewees.

Location	Gender	Age range	Years of seafaring experience	Years of pilotage experience
Area 1	3M, 1F	41 – 58	10 – 27	4 – 25
Area 2	3M, 1F	43 – 45	10 – 25	1 – 14

Figure 3: Example of video documentation in the simulation interview stage.

as this was the pilots' working language. All interviews were transcribed verbatim, and a consolidation of the data was carried out using the 4^{th} ACTA phase, the Cognitive Demands Table.

ANALYSIS AND RESULTS

In the following sections, the interviewed pilots will be referred to as SMEs (subject matter experts).

Task Diagram: Pilotage in Area 1

Figure 4 presents an overview of the tasks and related aspects of piloting a vessel within area 1. The figure is compiled from the respondents' task diagrams and reflects all tasks and aspects mentioned. There was a large degree of agreement among the area 1 pilots with regards to the mental model of there being three different phases of a pilotage; Preparation, Piloting and Maneuvering to berth.

The preparation phase starts during the transit from port to the vessel. The pilot familiarizes him- or herself with the vessel specifics, checks the current environmental conditions, such as wind and weather forecast, and prepares a passage plan for the voyage. The preparation phase ends in a Master-Pilot Exchange (MPEx) after the pilot has boarded.

During the piloting, which can be seen as the transit into the port area, the pilot and bridge team navigate the vessel jointly. Tools associated with Bridge Resource Management (BRM), such as closed loop communication, are used to maintain situation awareness and enable joint decision making. It is important to maintain a clear distribution of roles among the team members. This distribution is established during the MPEx. During the piloting,

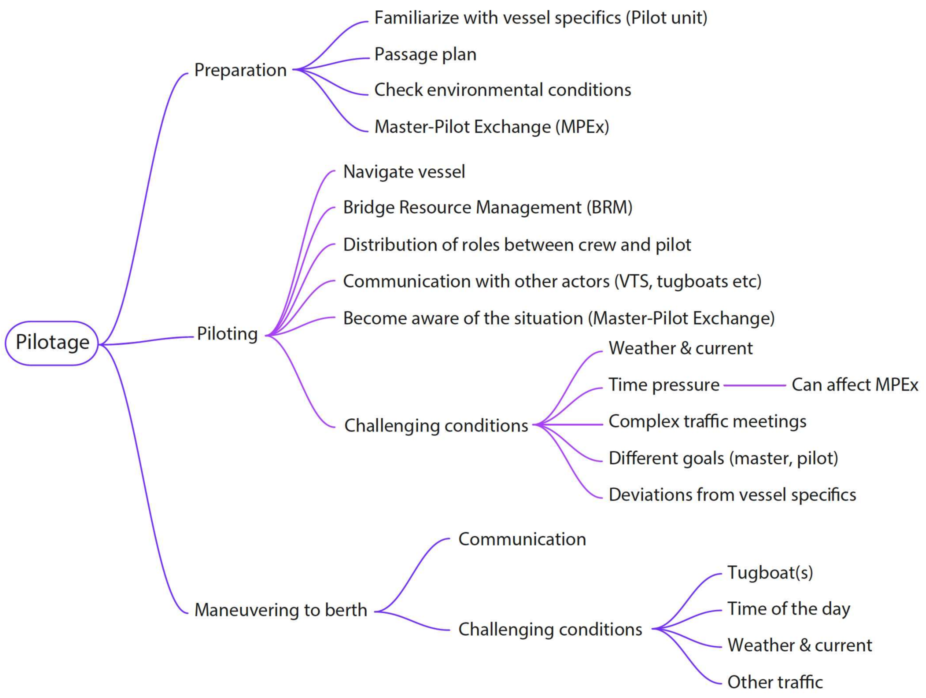

Figure 4: Task overview for pilotage in area 1.

communication among the team onboard and with other actors, such as the VTS, other traffic or potential tugboats, may also take place.

The SMEs emphasize several conditions that may increase the complexity and thus pose a challenge during the piloting phase. These conditions include time pressure, complex traffic meetings, deviations and deficiencies of the vessel being piloted, the state of the crew (in terms of well-being), as well as heavy winds, currents, and weather.

The last phase of the pilotage is the maneuvering from entering the port area to the assigned berth. This phase requires an increased amount of communication both within the bridge team and with other actors, such as the VTS or the linesmen. Several conditions may pose additional challenges, such as the use of tugboats, weather conditions, other traffic in and out of the port, as well as the time of the day.

Task Diagram: Pilotage in Area 2

Pilot area 2 is a larger pilot area with a longer transit period into port. Thus, although the pilotage can be split into the same three phases as pilotage in area 1, the tasks and associated aspects differ (Figure 5).

The preparation phase is started by receiving the pilot assignment through the designated pilot planning system (which pilots can access through a mobile device such as a smartphone). One expert also mentions that they check the planning system regularly, but in the other three cases SMEs identified the assignment as the starting point. Once the assignment is received,

Figure 5: Task overview for pilotage in area 2.

the pilots use their previous experience to categorize the vessel type and its potential requirements and challenges, as well as prepare a voyage plan. If certain facts in the assignment are identified as not possible to adhere to, such as an unrealistic Estimated Time of Arrival (ETA) in port, the pilot also acts as coordinator and communicates with other involved parties, such as the agent in port, the pilot planner, linesmen, and tugboat operator(s) to align the planning. Further, during the preparation phase the passage planning for the pilotage is conducted, and previously made plans are revised and updated based on available facts, such as other expected traffic in the area, destination for the specific vessel, weather, wind and current. One pilot mentions using mental simulation and 'what if'-thinking to explore potential risks and evaluate whether the plan is feasible.

The piloting through the area is characterized by transit navigation through the area, i.e. the bridge team uses mostly an autopilot (with some exceptions including hand steering with the help of a helmsman). The piloting phase is started by making boarding arrangements on the radio and boarding the vessel. After boarding, the MPex takes place during which the role of pilot and master during the pilotage are established, as well as the passage plan and vessel specifics. Like in area 1, communicating with the vessel's crew is seen as an important part of the pilot's work. Establishing a good contact with the bridge team is mentioned as a precondition for successful cooperation during the voyage.

The last phase of the pilotage is the maneuvering to berth, which includes both transit through the port channel, the maneuvering to berth and actual berthing. Since area 2 is a larger area and characterized by a longer transit period, this last phase is initiated through another MPEx to agree upon who will maneuver the vessel to the berth (master or pilot) and agree upon the specific arrangements for the operation.

KNOWLEDGE AUDIT

In the knowledge audit phase, six out of eight pilots identified *maneuvering* as the most cognitively demanding task when conducting a pilotage. One respondent chose to focus on a specific situation dealing with a *machine failure*, and another on the preparation, or *pre-maneuvering*, phase.

Maneuvering is considered cognitively demanding as it requires an intricate mixture of skills that are technical (such as understanding the vessel movements and impacts of weather and currents) and non-technical (such as communication, decision making and establishing leadership in the team) throughout the task execution. The SMEs emphasize the need to be flexible in the light of sudden changes in the operational conditions, and emphasize the complexity of their everyday work, as no pilotage is alike.

Past and Future (Predicting Chain of Events) and Big Picture

Pilots are experienced navigators and have served within the merchant fleet several years before being eligible to join the pilot organization. However, transitioning from a navigator into a pilot role is challenging, as the former is familiar with a specific vessel, while the latter needs to be an expert advisor for a large variety of vessel types in a determined sea area, where every piece of information, such as water depths, buoys, fairways etc. needs to be learned by heart. The SMEs within this study highlight that expertise is built through experience, rather than through being a good navigator. It is important to build a repertoire of vessel types, weather conditions, and social interactions with different crews to be able to quickly adapt to the conditions during a specific pilotage, and to be able to predict potential outcomes, developments and identify risks. Thus, building one's own knowledge and experience base is essential to become an expert pilot, and sets novices and experts apart within the domain.

While pilots go through an extensive training period, the SMEs emphasize that learning on the job is the key, i.e. both during the time as trainee where an experienced pilot acts as advisor and supervisor, as well as continuously during the work where every new situation a pilot faces becomes part of their knowledge base.

Job Smarts, Routines, Planning and Improvising

The SMEs highlight the importance of planning and conceiving several alternate plans as a precondition for being able to adapt and act quickly when the circumstances for the operation change. Planning normally occurs in the preparation phase where generic plans from a pilot's knowledge base are adapted to the anticipated operation. For this, vessel type, weather conditions, flag state and whether a specific vessel has been piloted before are essential indicators for whether a plan need to be changed. Unless the weather conditions are bad, i.e. strong winds or currents, most pilotages are considered routine operations, although with a large complexity in everyday work that requires the pilot to keep in mind many factors beyond their control.

The SMEs had difficulties to name specific job smarts or situations where a need to improvise occurs, mainly because they emphasized that there is always at least one backup plan prepared. Further, job smarts are rather seen as processes and strategies that are learned in the interaction with other pilots. This type of interpersonal and informal learning can be identified as a safety-increasing measure and essential to building expertise.

Cues and Self-Monitoring

The SMEs mentioned visual cues as important for the maneuvering and to determine whether a pilotage is proceeding according to plan, or if changes and adaptions are needed. Visual cues can both be information available in the pilot tablet, the bridge system or in the external environment. Further, verbalizing the passage plan during the MPEx also allows for self-monitoring and monitoring of the bridge team during the pilotage. If an open communication is established, the procedure of the operation can be monitored and challenged by both bridge team and pilot alike.

One of the SMEs specifically stressed that the difference between novices and expert pilots lies in the ability to anticipate deviations and make changes and adjustments ahead of time, while novices, with less experience, are prone to use corrective actions and become reactive, which often affects the quality of the outcome more. Thus, it can be concluded that the ability to self-monitor and regulate is a facet of expertise built through work experience.

Further, despite the emphasis on the maneuvering as being cognitively demanding, this SME reasoned to a large extent about the importance of social interactions and cues provided in the social environment onboard. Social aspects include finding one's role in the bridge team during the operation and establishing a clear communication among the team members to coordinate the work. Maritime resource management (MRM), which is also referred to as Bridge Resource Management (BRM) by the experts, provides tools and a mindset that can help to support the pilot during the work.

It is emphasized that the ability to take on different roles in the team as well as the ability to communicate clearly and establish leadership are important to support the safe conduct of the operation. Roles mentioned by the SMEs range from being a support to the bridge team and mainly monitoring their actions, to actively taking control within the navigation by providing instructions to the helmsman and master. Signs of stress, incomplete communication or mismatches between what is communicated and what is done, can be used as cues to change one's behavior and adapt to the needs to the crew.

DISCUSSION

In comparison to "traditional" studies utilizing ACTA to provide input into training or technology design, this study has tried to explore aspects of expertise in everyday work that involves great adaptability to changing circumstances.

The results show the importance of operational experience and knowledge transfer through interpersonal and informal learning as key components to becoming an expert pilot. Unfortunately, since this type of learning occurs informally, many important lessons might only be shared among a limited group of individuals. It also makes it difficult to draw practical conclusions about how to improve formalized pilot training and education.

While the educational and professional backgrounds as navigator are preconditions, the actual pilotage expertise is built on the job as the individual creates a knowledge and experience base, which can be used to during the preparation phase of a pilotage and enables quick adaptions and the ability to foresee potential needs for corrections.

This study also identified certain difficulties with using the ACTA probes on a type of profession that, for all its planning ahead and protocols, is unpredictable in many micro-perspectives and constantly shifting in response to weather, vessel peculiarities and the state of the crew (in a social sense). In contrast to other professions that have been extensively studied with ACTA before, the safety-criticality of pilotage is not event-based, but rather dependent on constant monitoring and adaptability to shifting conditions. Pilots were sometimes not sure how to fit certain probes to the "right way" to carry out pilotage, nor were they sure whether to call any behaviour a "job smart" or "trick of the trade" as no two pilotage situations are alike, even within the same port.

CONCLUSION

Conclusions drawn from the ACTA's first two stages highlight the mentally and socially complex task that piloting is, and that the pilots use great discernment and acuity when processing verbal as well as non-verbal input, alongside human as well as non-human movements (the latter coming from the vessel and surrounding bodies of air and water).

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