Identifying cognitive challenges for safe ship overtaking in restricted waterways

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Research Article

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Abstract

Navigation in constrained waters is a cognitively challenging task for seafarers requiring the combined assessment of various elements to perform it with safety. This paper presents our approach to make sense of the dynamic, uncertain, and complex work domain of sea pilotage. We aimed to obtain a detailed description of the overtaking manoeuvre and to understand the cognitive processes of mariners when they perform this task in confined waters. To achieve this, we performed a qualitative study using an adaptation of Applied Cognitive Task Analysis with five highly experienced sea pilots in northern Germany. Based on the content analysis of the interviews and the other data collection activities, we have identified six phases of the overtaking task and twelve high level cognitive challenges that significantly affect pilots’ decision making and situation awareness during overtaking. The main output is a Cognitive Demands Table where the findings on the cognitive challenges, common errors, strategies, and cues are organized. The analysis of our results captured pilots’ insights on decision-making and expertise, the role of communication, planning and foresight and how the cognitive challenges correspond to situation awareness. Finally, practical implications for the design of the workplace and operating procedures, the training of pilots and the limitations of the study are discussed.

1 Introduction

Ship navigation is a complicated task, associated to various kinds of challenges and risks. It requires the successful performance of operations that ensure the safe passage of vessels into and out of port through channels and open waters, while making predictions about possible traffic developments (Chambers and Main 2015). The combination of ships’ large inertia and close proximity demands the careful preplanning of the manoeuvres, so that a passage plan can be successfully completed without the disastrous consequences of incorrect decisions (Wickens et al. 2020). Additionally, navigators also need to be aware of multiple factors such as bathymetries, hydrodynamics, meteorological conditions, and other ships’ movements that are not directly observable but need to be obtained and assessed from a number of sources, including an increasing number of technological aids (Lee and Sanquist 2000; van Westrenen and Praetorius 2012). Therefore, modern day navigation is an inherently complex cognitive task involving multiple and often uncertain variables, the perception and comprehension of an increasing volume of information, and the coordination of navigational tasks and responsibilities. All the above elements demand quick, precise and reliable processes, often under time pressure before making critical decisions. (Hockey et al. 2003; Hutchins 1995; Patriarca and Bergström 2017; Prison et al. 2013; Sharma et al. 2019).

The close manoeuvring phase refers to navigation in restricted waterways or pilotage waters (National Research Council 1994), such as harbours or narrow channels, where vessels of any size may experience the hydrodynamic effects between ships, and between ship and bank or sidewall in the proximity of bank. Low under keel clearance, narrow channel/fairway, high wind velocity and strong currents are examples of such limits, along with poor visibility and dense traffic can result in the state of navigating in marginal conditions with serious risks (Akten 2004; Rønningen and Øvergård 2017; Wild 2011). If these effects exceed a certain level, they can cause errors in manoeuvring which can lead to marine accidents like collision and grounding (Chakrabarty 2021; Du et al. 2018; Lee and Lee 2008; Prison et al. 2013).

About 90% of all marine accidents happen in confined waters such as channels and inshore traffic zones (Cockcroft 1984 as cited in Hockey et al. 2003). The most usual types of encounters between two vessels in these waterways are a head-on situation or an overtaking situation. The overtaking encounters take more time and a longer distance than head-on encounters since both vessels sail in the same direction, and the safe lateral distance between overtaking vessels is smaller than between head-on vessels (Zhou et al. 2023). The geometry of the vessels, the transverse and longitudinal distance between the vessels, the water depth and the forward speed will be integrated together, making the overtaking interaction very complex (Yuan et al. 2015). Overtaking interactions that involve more than two vessels are even more complicated and are a typical scenario for harbours or waterways (National Research Council 1994).

During navigation through near-shore and inshore waters, the ship bridge crew collaborate with a maritime pilot (hereafter referred to as pilot), who directs and controls the movement of the vessel to ensure a safe passage. Pilots are well-trained and highly skilled professionals, with expert knowledge of local waters and special ship handling skills (Andresen et al. 2007; Darbra et al. 2007; National Research Council 1994). Still, controlling and executing manoeuvres such as overtaking during pilotage in conditions with critical environmental or intense traffic aspects can be challenging and cognitively demanding even for expert pilots, since it involves managing navigation and collision avoidance activities while avoiding the major risk of grounding (Chauvin et al. 2008; Langard et al. 2015; Orlandi and Brooks 2018).
Previous studies have stated that decision making is one of the major causes of maritime accidents and incidents (Chauvin and Lardjane 2008; Graziano et al. 2016; Yildirim et al. 2019; Wagenaar and Groeneweg 1987) and inappropriate situation awareness is often the precursor of a poor decision (Chauvin et al. 2013). The Manila amendments have addressed situation awareness (SA) and decision making as key components of sound seamanship (Cordon et al. 2017; Øvergård et al. 2015). Endsley (1995) has defined SA as "the perception of the elements in the environment within a volume of time and space (Level 1), the comprehension of their meaning (Level 2) and the projection of their status in the near future (Level 3)". Research on cognitive demands that affect decisions in critical situations has shown that problems in interpreting intentions or predicting the actions of other vessels was one of the most common sources of near-miss incidents (Hockey et al. 2003) and the necessity to investigate the mariners’ decisions in critical conditions has been implied by researchers in the domain (Chauvin et al. 2013). The ability of the navigator to maintain a clear and updated status awareness (i.e. being informed of the current status of the vessel, the passage plan and the presence of current and near-future dangers to the safety of navigation) represents the most critical element for the prevention of errors and the successful performance in any manoeuvring situation (Cordon et al. 2017; Stanton et al. 2017).

While technological innovations aim to mitigate these difficulties, they may also burden the human operator with increased cognitive demands. Many navigation errors result from misinterpretations or misunderstandings of the signals provided by technological aids (Lee and Sanquist 2000). Most of the calculations for a successful manoeuvre are to be done mentally, because nearly no automation support is available for complex manoeuvres (Benedict et al. 2016). Additionally, in such environments navigators continuously update their mental models of the current system state (Levenson 2011). Therefore, as suggested by Lützhöft and Dekker (2002), the challenge for the technological aids is to support the navigator, and by extension the pilot, not only in foreseeable standard situations but also during critical manoeuvring, where navigation is demanding and safety critical.

Although limited, there are some recent studies that yielded interesting findings and indicated the need to bring more insight into aspects of decision-making during piloting in demanding manoeuvres. Butler et al. (2022) utilised an integrated systems thinking framework to investigate how pilots make decisions and what factors are perceived to influence their decisions. Their findings illustrate how the intuitive and analytical decisions of the pilots are influenced by many diverse factors from across the maritime system. Sharma et al (2019) interviewed 7 experienced navigators in an exploratory study based on the GDTA methodology to identify the SA information that is required to execute the decisions for pilotage on a merchant vessel. Their results indicated that navigators depend to a great extent on the pilot for supplying up to date localized information in port areas. These studies are a significant contribution to the domain, but there is no mention or analysis of specific manoeuvres such as overtaking where a high level of expertise is required or phases of operations that are cognitively demanding for the pilots. Haffaci et al. (2021) conducted a Goal-Directed Task Analysis (GDTA) at Trois-Rivières port in Canada to extract the SA information requirements of 8 experienced pilots for the docking manoeuvre. They claim that their study is the first to target a specific manoeuvre in compulsory pilotage area but it's unclear whether their findings on the impact of SA and information requirements on the decision making for docking can be broadly applicable to other complex manoeuvres. Also, these studies did not analyse the cognitive processes of experts during decision making that results in safe pilotage operations.

The aim of the research presented in this paper is twofold: first, to examine the decision-making processes of maritime pilots in demanding manoeuvring tasks within confined fairways and second, to investigate and represent in a systematic way the cognitive challenges that affect these processes. For our purposes, we have conducted a case study based on a realistic navigational scenario of overtaking in restricted fairways where we adapted the knowledge elicitation technique known as Applied Cognitive Task Analysis (ACTA). We present our methodological approach and our findings on the cognitive challenges that influence decision making during pilotage for safe overtaking. Finally, we discuss our results, how they extend the knowledge on pilots’ decision making and share our reflections and the implications for this particular domain.

2 Background

2.1 Pilotage

Pilotage is a profession as old as shipping itself. Since the early days of marine navigation, vessels entering or leaving port, or navigating other hazardous waters, have been guided by pilots (IMO 2022). Historically, people with extensive knowledge of local waters, weather, tides, shoals, and other conditions have been employed on board ships to ensure the safe passage of vessels into and out of their destination harbours (Chambers and Main 2015). For example, fishermen in the river Elbe in Germany acted as pilots as far
back in the 14th century (Hamburg Pilot Association 2019). Nowadays, the pilotage services are a necessity wherever navigation may be considered dangerous, especially in occasions when the master of a ship is unfamiliar with the area. Estuary and river navigation and manoeuvring in confined waters, ports, or canals, demands great nautical skill (IMPA 2022).

The maritime transportation in modern Europe is characterized by increased traffic between the large European hub ports, which translates into shorter sailing and port turnaround times. The navigation areas also include dredged channels that provide access to ports, where medium deep, shallow, and very shallow water is common. However, most ships are designed and optimized for navigation at sea and not for sailing in areas characterized by limited depth and width, the vicinity of banks, currents, and speed restrictions where they can be often confronted with completely different environmental conditions (Vantorre et al. 2017). As a consequence, the safety margin of the narrow waterways decreases even more as the merchant vessel sizes and velocities increase (Norros 2004). Further, ships are sometimes manned by smaller and often less experienced crews and along with the technological advances in shipping, pilotage is regarded as a demanding and complex task (Lappalainen et al. 2014).

In such situations, the successful navigation of a ship, especially in constricted areas such as fairways that lead in and out of ports, rests largely with a single individual—the pilot, a professional who is asked to demonstrate qualified knowledge, be responsible and decisive (Andersen et al. 2007; Wild 2011). Within a very short period of the time, pilots have to acquaint themselves with the characteristics and manoeuvring of an unfamiliar vessel, while taking weather conditions, currents and tides into account, before setting course and giving instructions to sail (EMPA 2021). In addition to the provision of their regional knowledge and expertise, pilots act as partners of the captains by supporting them to communicate efficiently with the shore and the tugs, often in the local language. Further, pilots are trained professionals on policies regarding the protection of the marine environment and the safety and efficiency of the flow of marine traffic (IMO 2022; IMPA 2022).

Ship bridge systems have evolved to aid the SA of the navigators, facilitate risk assessment, and improve the safety and efficiency of navigation (IALA, 2021). The modern ship bridge systems include Multi-Function Displays (MFD) that present much of the information. They consist of several systems that can be chosen based on what information is necessary for the navigator. These systems are the Electronic Chart and Display Information System (ECDIS), the Automatic Identification System (AIS), the Global Positioning System (GPS), the radar, the conning display that may include orders, status information, route, and data, such as the Estimated Time of Arrival (ETA) and autopilot mode, and more data systems on environment, etc. In addition to the above, pilots use the Portable Pilot Unit (PPU), a carry-on personal navigational aid that has become one of the most widespread pilotage tools. The PPU provides pilots with an electronic chart that can enhance situational awareness in a format with which they are familiar. The PPU also includes features and data that might not be otherwise available on ECDIS, such as the most up-to-date local hydrographic data or live tidal data, in-built accelerometer for heel and trim angle representation (Lahtinen et al. 2020; Rouse 2022).

**2.2 Human Error and Situation Awareness in using Ship Bridge Systems**

The human element prevails as a major factor in 58–85% of maritime accidents worldwide (Baker and McCafferty 2005; Grech et al. 2002; Lützhöft and Dekker 2002). According to statistics from the European Marine Casualty Information Platform, 89.5% of the reported safety investigations from 2014 to 2020 have human action accident events or contributing factors catalogued as human behaviour, so they are affected by the human element. More than half of the casualties and incidents in the European area have taken place in internal waters, whereas the sub-category port area represented 41.5% of all accidents (EMSA 2021).

With the introduction of technological aids, the act of navigation has progressively changed towards monitoring the progress of the vessel on displays and other instruments (Procee et al. 2017). When fulfilling the task of manoeuvring, the pilots gather the information devices and displays, then go through their experience and knowledge to comprehend the situation at hand, and finally use their mental models to judge what information is more crucial than other information and build SA (Pohat et al, 2014). As the navigators try to manage all these features, modes, and options across a diversity of operational circumstances, bridge system complexity becomes an issue. Failures to recognize this complexity are often categorised as ‘human error’. This is evidenced in several maritime accidents in which seafarer’s ‘lack of equipment familiarization’, ‘complacency’, ‘lack of training’ and ‘poor lookout’ are often cited, to the neglect of design or manufacturer shortfalls (Grech and Lemon 2015; Leveson 2011; Lützhöft and Dekker 2002).

**2.3 Cognitive Task Analysis – ACTA**

While traditional Task Analysis methods offer a physical description of the actions that occur within a complex system, Cognitive Task Analysis (CTA) methods focus on describing the cognitive processes and elements that determine goal generation, decision making, thought processes, judgment, etc., during task performance. CTA methods use in-depth interviews with subject matter experts (SMEs)...
for data collection and focus on yielding information about the cognitive strategies and challenges that are used to accomplish a task, such as situation assessment techniques, recognition and perception of critical cues and metacognitive activities (Drury and Darling 2007; Militello and Hutton 1998; Stanton et al. 2013). CTA methods can support the interviewed SMEs into articulating their domain knowledge and the researchers into identifying what information is important and related to the cognitive aspects of the work (Brödje et al. 2010), therefore they are a suitable means to elicit information in a systematic manner regarding expert decision making in pilotage.

The most frequently cited variants of CTA, include the Goal Directed Task Analysis (GDTA) by Endsley and Jones (2012), the Critical Decision Method (CDM) by Klein, Calderwood and MacGregor (1989) and the Applied Cognitive Task Analysis (ACTA) by Militello and Hutton (1998). We decided to use the ACTA technique because it can support practitioners in examining in depth difficult judgements and decisions, attentional demands, critical cues and patterns as well as problem-solving strategies that are required for the proficient performance of a task (Gore et al. 2018). ACTA is a flexible method for work domains where observational data are difficult to collect yet provides the means to extract the knowledge and codify the complex decision-making skills into comprehensible form for the analysts and requires less training, resources and time for its application compared to other CTA approaches. ACTA has been successfully used to understand expertise in a wide range of areas including: business aviation piloting (Latorella et al. 2001), helicopter pilots (Tušl et al. 2020; Minotra and Feigh 2017), unmanned aircraft system pilots (Lercel and Andrews 2021), unmanned vehicles (Drury and Darling 2008), medical contexts (Pickup et al. 2019; Morozova et al. 2017; Craig et al. 2012; Militello and Hutton 1998; Militello et al. 1997), crime scene examiners (Martindale et al. 2017), financial decision-making (McAndrew and Gore 2013), weather forecasting (Hoffman et al. 2006) and high-level coaches within strength and conditioning (Downes and Collins 2021). Thereby, we consider it fitting to help us better understand marine pilot performance in critical manoeuvres.

The method consists of four complementary techniques each of them aiming to derive different aspects of cognitive skills that all add up to comprehensive results (Militello and Hutton 1998; Stanton et al. 2013):

1. The Task Diagram (TD) interview provides the analyst with a broad overview of the studied task and highlights the difficult cognitive portions of the task to be examined in the later phases.
2. The Knowledge Audit (KA) highlights the aspects of expertise that are necessary for a specific task or subtask. As each aspect is revealed, the SME is probed for specific examples in the context of the job, cues and strategies used, and why it presents a challenge to novices.
3. The Simulation Interview (SI) allows the interviewer to probe the cognitive processes of the SMEs within the context of a specific scenario. The use of a simulation or scenario provides job context that is difficult to obtain via the other interview techniques, and therefore allows additional probing around issues such as situation assessment, how situation assessment impacts a course of action, and potential errors that a novice would be likely to make given the same situation.
4. Finally, the Cognitive Demands Table (CDT) systematically combines and synthesizes the data, so that it can be directly applied to a specific context by the analyst.

3 Methods

For the purposes of the study, we contacted several sea pilot associations that operate in the maritime traffic zones of Jade, German Bight and Bremerhaven - Weser in the North Sea. The limitations of the location were due to reasons of proximity and ease of access for further studies. After establishing communication with a corresponding high-ranking marine pilot in one of them, a series of data collection and analysis activities were conducted to tackle the research questions explored in this study, capturing both contextual and sequential aspects of navigation in confined waters.

3.1 Domain familiarization

A series of training sessions, open structured interviews and field observations were conducted to obtain familiarization with various types of ship bridge environments and manoeuvring activities. Initially, the first author participated in a course that included attendance of simulation sessions as member of a ship bridge crew in performing standard manoeuvres. Following the training, we conducted an exploratory review on ship bridge equipment interfaces, IMO regulations, procedural manuals, and roles and responsibilities of pilots and the ship bridge crew. We also studied 17 official reports issued by the Federal Bureau of Maritime Casualty Investigation (Bundesstelle für Seeunfalluntersuchung 2022) in Germany on incidents and accidents that occurred between the years 2008–2015 in the waterways within the German Bight region in the North Sea, where pilotage is compulsory for vessels with specific
characteristics (Federal Maritime and Hydrographic Agency 2021). Afterwards, the first author interviewed two highly experienced sea pilots from one district in Bremerhaven to obtain an overview of critical manoeuvres and additional background information using an abstracted scenario where two vessels meet in a narrow channel.

A field trip was organized with the support of the corresponding mariner to observe the activities of a pilot on duty and a ship bridge crew during an inbound and an outbound voyage with different ships in the maritime traffic zones of Jade, German Bight and Bremerhaven - Weser in the North Sea as seen in Fig. 1. Our approach was to shadow the pilot as he performed his tasks and ask questions whenever clarification was needed. The collected data include field observation notes, photos and video recordings of the main responsibilities, as well as a brief description of the equipment and work settings in both ship bridge environments. Further details on the explorative interviews and the field trip can be found in Parisi and Fränzle (2017). The overall findings from the familiarization activities were progressively evaluated with a former navy mariner, the corresponding pilot, and human factors researchers until the task under analysis was shaped. Specifically, the mariners provided input in the scenario creation (ship models, traffic situation, distances) and human factor experts provided feedback on the methodology.

### 3.2 Applied Cognitive Task Analysis

Our approach for implementing ACTA is based on the adaptation of the methodology as described in Brödje et al (2010) and Stanton et al (2013). The first step is the Task Diagram (TD) interview, where participating SMEs are asked to describe the overall task in three to six sub-steps/subtasks. To support the comprehension of the question, Militello and Hutton propose practitioners of ACTA to use an example of the fire ground command that attend to a burning building (1998). We had also prepared a TD for car overtaking to use as a last resort in case any of the SMEs faced difficulties with comprehending the questions for constructing a TD. The second step was the Knowledge Audit (KA) interview that we used to elicit information about a pilot's knowledge at a broad level, while potentially identifying instances of expertise applied in real-world situations and perceptual skills including cues and patterns needed for overtaking. The third phase was the Simulation Interview (SI), where we adapted the technique used by Brödje et al. (2010) and built a half interactive low fidelity simulation to serve the purposes of our research. Finally, we reviewed all our gathered data and conducted a highly structured content analysis to develop knowledge representations. We used the Overview Task Diagram and the Cognitive Demands Table representation frameworks, as defined by the ACTA toolkit.

#### 3.2.1 Participants

Selection of the participants for the ACTA interviews was done by the corresponding pilot on site, based on which pilots would be available at the time for data collection and had experience in overtaking manoeuvres. Prior to their recruitment, the SMEs were informed of the purpose and the content of the interviews. All five pilots were on active duty. Their total seagoing experience ranged from 12 to 37 years ($M=23.4$ years) on the date of the interviews. They had served as master mariners from 2 to 28 years ($M=10.8$ years). All five participants were male and active in the Pilots Association of Weser 2 / Jade and their experience in pilotage ranged from 1 to 16 years ($M=9.3$ years) on the date of the interviews.

#### 3.2.2 Procedure

Initially, two pilot runs of the interviews were conducted with human factors experts to refine the questions to be used, the duration of each interview and the flow of the process. Following a brief introduction on the purpose of the study and how the data collection will be performed, participants signed the consent forms that were emailed to them before the interviews. At the end of the procedure, they filled in data forms on their seafaring experience and demographic data. Finally, they were offered a gift bag as appreciation for their contribution to the studies.

First, we performed the Task Diagram (TD) interview to obtain a high-level description of overtaking. The prompt question was “Think about what you do when you perform overtaking of a ship during the fairway segment from the south end of the container terminal until where the fairway gets wider. Can you break this task into 3–6 steps?” All participants were asked to write their own TD on paper and notes were taken in parallel by the interviewer during the discussion. The pilots were also asked to identify aspects of the task that are cognitively demanding using the prompt question “Please encircle the steps where you need to think hard and make complex decisions”.

Following the TD interview, the Knowledge Audit (KA) interview was done for the subtask(s) that each participant identified as cognitively demanding. The six basic probes (Past and Future, Big Picture, Noticing, Job Smarts, Improvisation, Self-Monitoring) and the optional probes (Anomalies, Equipment Difficulties) were used. The probes were adapted by the research team to better fit the
pilotage context and were worded in a manner that first clarified the type of the question (e.g., “it is important not to waste time in seafaring but also to save resources and navigate with safety”) and then directly addressed overtaking (e.g., “So when you overtake, have you found any ways that are useful for you to work in this logic?”). When participants responded positively, they were asked to provide examples from their experiences. Follow up questions were asked to clarify the participants’ answers as well as to further explain the probe in case they were unable to offer a reply immediately. (see Appendix 1.1 for the full list of probes). A Knowledge Audit Table was used to enable notetaking for this phase (Appendix 1.2).

For the third phase of the Simulation Interview (SI), we created a scenario based on elements from investigation reports, including real events, conditions and other situation characteristics and data from the domain familiarization phase. The scenario, designed with the help of a very experienced pilot from the Bremerhaven station, recreates a typical everyday overtaking activity in outer Weser. We decided to include a third vessel in the situation of the scenario, since such complicated encounters are common in busy waterways (National Research Council 1994). An image that displayed static geographic information from a segment of the Outer Weser region was created by capturing the status of the fairway on July 19th, 2017 using the OpenSeaMap project (OpenSeaMap 2022) and included only sea marks and marine traffic information. It was printed and placed on a table and thin plastic transparent sheets were fitted on top of the map (Fig. 3).

All participants were provided with the scenario information as seen in Table 1. Additional information about environmental conditions and ship characteristics were provided in printed format and on a laptop screen.

<table>
<thead>
<tr>
<th>Scenario for the Simulation Interview.</th>
</tr>
</thead>
<tbody>
<tr>
<td>You are the pilot on the container ship GUAYAQUIL that is set to arrive in the Bremerhaven container terminal. Ahead of you there is the coaster vessel MARINO that moves strict to the right side of the fairway, and you prepare to overtake. Another big vessel, the car carrier OTTAWA EXPRESS is outbound.</td>
</tr>
<tr>
<td>Weather: T: 18-19°C, wind at 17Km/h (3Bft) SW, gusts at 33Km/h(5Bft), visibility 15km, cloudy</td>
</tr>
<tr>
<td>High tide 3.37m at 10:52 AM, Low tide 0.5m at 5:25 PM</td>
</tr>
<tr>
<td>Current: 3.3 knots on the surface and 2.5 knots at a depth of 2m below mean low water level</td>
</tr>
<tr>
<td>Time is 12:00</td>
</tr>
</tbody>
</table>

After the participants familiarized themselves with the scenario and the settings, they were asked to verbally walk the interviewer through the process of overtaking, to identify any important aspects of the task and the critical cues used in their decision process, and to mention any major events that could interrupt them. The participants were asked to think aloud as they interacted with the simulation. They used model vessels made of plexiglass and non-permanent markers to mark the initial and end positions of the ships, the courses, and any information of interest regarding the overtaking manoeuvre. Questions such as "What are possible important events that might occur during your shift?", "What can cause trouble?" were used to enable the discussion.

All interviews were conducted by the primary researcher alone on the premises of the Pilots Association of Weser 2 / Jade within three days. Each interview lasted between 2 and 3 hours on average, including a fifteen-minute break between the KA and SI phases in order to setup the material for the SI and the video camera for the recording. The TD and KA phases were recorded in audio and the SI phase was additionally captured with a video camera. The verbal and video protocols of the interviews were subsequently anonymized. Figure 2 shows a diagram that summarizes the research activities and their outputs.

### 3.3 Data analysis

Our analysis was based on notes and data from all interview sessions in combination with findings from the domain familiarization stage. The process focused mainly on various aspects of decision making, cognitive challenges, instrument usage and information demands during overtaking. The audio recordings were used for the actual transcription of everything said and the video recordings were used complementary to describe what vessels or areas the participant was pointing at during the SI. The content of the video data was added to the same transcription as the voice recording, resulting in one single transcription per participant.
The transcripts were then imported in the ‘Dovetail App’ (2022) to perform content analysis. We first defined a list of concepts that facilitated the analysis based on the derived insights from our literature review and the recommended sample headings from the ACTA creators (difficult cognitive element, why difficult, common errors, cues and strategies used). Guided by the predefined concepts, we collated key points and raw data quotations from the transcripts and assigned them codes by identifying patterns in meaning across the data. The codes arising out of each interview were constantly compared against the codes from the same interview, and those from other interviews. For our study, we combined both a deductive and inductive approach to coding. Even though we started the process deductively with a set of concepts, we inductively created additional concepts as we created codes that did not fit within the initial concepts. Finally, we iteratively reviewed the concepts and codes and compiled the Cognitive Demands Table (CDT) to consolidate and synthesize our data.

4 Results

Results are presented in the following sections as follows. First, we present some of our observations from the field trip during the domain familiarization phase. Second, we present the Overview Task Diagram with illustrative responses by the participants to demonstrate our findings. Then we present indicative results from the Knowledge Audit phase and the Simulation Summary. We then provide an analytical summary of the cognitive challenges identified across our sample as a whole in the Cognitive Demands Table. For each of these cognitive challenges, we identify the reasons why they are difficult, what errors pilots commonly make, the strategies used to work through the cognitive difficulties and the cues and sources of information in relation to each challenge.

4.1 Observation of pilotage

We were fortunate to observe the bridge team performing an overtaking manoeuvre during the second voyage of the field trip in the German Bight fairway. Our vessel, a general cargo ship, was moving inbound to Bremerhaven when the fairway got narrower from 300m to 220m. The traffic increased, because an oil tanker 70m long was sailing in front of our vessel with slower speed and a dredger was approaching from the opposite direction. The crew immediately assessed the fairway status and the available space. At that point, there was communication between the officer on watch (OOW), who is a deck officer with the duties of watch keeping and navigation on a ship’s bridge, the pilot, the crew from the dredger and the Vessel Traffic Service (VTS) operator about the situation. The dredger informed the OOW of their intentions to exit the fairway and proceed to the dumping ground that is assigned for dredgers north of buoy 34 outside of the fairway (see Fig. 1). The act of the dredger’s crew to share their planned route enabled the overtaking manoeuvre and the VTS operator did not intervene. The pilot explained that without this action by the third ship, the overtaking might not have occurred, because a possible meeting in the fairway later could have become critical for all vessels.

Another notable observation was that 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 PPU in the second vessel, which had a ship bridge system of recent technology. Autopilot was used at all times during the second voyage. The master was always in control in both ships and all pilots had advisory roles.

4.2 Overview Task Diagram

We have compiled the replies from all 5 SMEs into one single Overview Task Diagram (OTD) as depicted in Fig. 3. Examples of participants’ responses illustrating these themes are evidenced in Table 2 responses. The OTD consists of six steps and reflects the consensus among participants about the sequence of the cognitive tasks performed during overtaking. Four of the participants mentioned gathering information and checking the status of their own vessel and the vessel to be overtaken (VtO) as the first step they do, while one mentioned that checking if there is enough room for the manoeuvre is the first step. All participants mentioned the assessment of the fairway conditions and calculating and maintaining the safe speed difference and distance between their own vessel and fairway limits/other ships as necessary steps for deciding on overtaking. They also referred to the communication aspects of the task and mentioned that they will contact the other vessels involved in the situation if necessary, as a courtesy of good seamanship. The final step to all separate Task Diagrams was returning to the right lateral position in the fairway.

Assessing the fairway conditions and the status of the vessels, along with determining the safe speed and passage constitute the preplanning phase that leads to the decision of proceeding with overtaking or not. If the pilots contact the other vessel(s), they might do so within or right after the completion of the preplanning phase.
Table 2
Examples of participants' responses for the Overview Task Diagram stage. Participant number is in parentheses next to each response.

<table>
<thead>
<tr>
<th>Task Diagram Stage</th>
<th>Example of participant response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assess fairway conditions</td>
<td>&quot;I have to clarify if the fairway is free to do this manoeuvre when I check the traffic situation&quot; (P5)</td>
</tr>
<tr>
<td></td>
<td>&quot;I have to evaluate the situation regarding the traffic situation on the river. Dredgers and so on, Opponents and so on, sailing ships, it doesn't matter.&quot; (P3)</td>
</tr>
<tr>
<td>Collect information and check status of vessels</td>
<td>&quot;the first information I have for my own ship, size of my own ship, draft of my own ship&quot; (P2)</td>
</tr>
<tr>
<td></td>
<td>&quot;The size of the vessel, the speed of the vessel, destination of the vessel, size is very important even if you are faster than the other one ahead of you&quot; (P4)</td>
</tr>
<tr>
<td></td>
<td>&quot;an overview about the equipment. What kind of... Is he on autopilot, is he on manual steering, what kind of rudder&quot; (P3)</td>
</tr>
<tr>
<td>Determine the safe speed and passage</td>
<td>&quot;enough room, enough speed, I have to increase the speed to overtake somebody, or the other one has to slow down...&quot; (P1)</td>
</tr>
<tr>
<td></td>
<td>&quot;Speed difference and distance to the vessel to overtake. So that means how long it will take me to overtake the other vessel ... due to the size and draft the tide level of the river.&quot; (P2)</td>
</tr>
<tr>
<td>Contact other vessels (if necessary)</td>
<td>&quot;Depends on the type of the vessel or several parameters are important otherwise it would be clear, you are smaller, you are very slow, I am overtaking you, I do not have to call my colleague.&quot; (P1)</td>
</tr>
<tr>
<td></td>
<td>&quot;maybe I will ask also the one who is to be overtaken if he can help me and reduce for a short while&quot; (P2)</td>
</tr>
<tr>
<td>Perform overtaking</td>
<td>&quot;If everything says yes, if all parameters are not dangerous, and I start to overtake, I'm doing it then. I try to make the process as quick as possible and also as safe as possible&quot; (P2)</td>
</tr>
<tr>
<td></td>
<td>&quot;when I have an agreement to overtake I start my manoeuvre with of course good seamanship, overtaking in safe distance&quot; (P5)</td>
</tr>
<tr>
<td>Monitor the situation and continue on a safe course</td>
<td>&quot;I monitor this very close all the time, the time of overtaking and also if there are some more inbound traffic that I didn't see, for example small sailing vessels you have not in your mind and you see in the last moment or something, leisure crafts.&quot; (P2)</td>
</tr>
<tr>
<td></td>
<td>&quot;I'm focusing more what is happening later on with the ship I am passing quite fast&quot; (P3)</td>
</tr>
<tr>
<td></td>
<td>&quot;I really have to monitor this meeting point all the way...till the overtaking manoeuvre is over.&quot; (P4)</td>
</tr>
</tbody>
</table>

4.3 Knowledge Audit

The KA phase focuses upon a cognitive sub-task elicited from the TD each participant created. For each participant, the subtask that was identified as the most cognitively complex component formed the focus for the rest of the interview. The data from the TD phase indicated that there was not consistent phrasing among participants for describing sub tasks to the primary task of overtaking. Their responses are aggregate reflected in the steps Assess fairway conditions, Collect information and check status of vessels and Determine the safe speed and passage as mentioned in our TD. It should also be noted that two participants identified more than two steps as cognitively challenging, however all of them, in one form or the other, mentioned that the aforementioned three steps in the preplanning phase require significant cognitive skills.

Participants' responses to the KA probes showed the varied ways that the pilots approach and resolve situations, and the problems that may occur when overtaking. Each case demonstrates how pilots rely on their expertise to improve their job performance by using their tacit knowledge to perform effective situational assessment and develop appropriate solutions. Some of the presented results are not exact extracts of the participants’ responses for each associated prompt. For example, some participants would mention a job smart or something they notice when prompted to talk about the big picture. Our data also included sixteen narratives of incidents from the participants that were directly or indirectly related to the task of overtaking during the KA phase.

Individual knowledge audit tables were initially developed for each participant and contained in total 68 responses to the probes that were later assessed for similarities and overlapping content. This process resulted in a consolidated list of 60 responses, subsequently integrated into a single KA table. The consolidated KA contains all necessary elements for a holistic understanding of critical facets of domain knowledge and expert–novice differences in overtaking and pilotage. Examples of the most pertinent responses to each probe question are presented in Table 3.
Table 3
Examples of participants’ responses on Knowledge Audit probes for overtaking from the integrated KA table. Participant number is in parentheses next to each response.

<table>
<thead>
<tr>
<th>Probe</th>
<th>Number of responses</th>
<th>Example of participant response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Past and Future</td>
<td>7</td>
<td>“I was just hearing these guys talking (on VHF) to overtake and I said ‘okay, if I overtake this one now, we will meet all close together so I will stay behind’” (P2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>“you can try it, but you have to keep it in mind due to slack water we'll take much longer than you think.” (P3)</td>
</tr>
<tr>
<td>Big Picture</td>
<td>7</td>
<td>“I am of course informed about the traffic, about the vessels underway. One of the big points is which size vessels are going where at the moment. Cause opposite traffic, big draft container vessels, there is no chance to overtake another vessel ahead of me. Cause there is not enough space.” (P5)</td>
</tr>
<tr>
<td>noticing</td>
<td>13</td>
<td>“I looked, that it's coming closer and closer due to the increasing speed it was suctioned and he didn't realize so I talked to him...” (P1)</td>
</tr>
<tr>
<td>Job smarts</td>
<td>7</td>
<td>“all vessels with pilot, I get in contact with my colleague and sometimes we do the situation together cause sometimes a vessel ahead say ‘oh don’t forget there is also inbound so and so, you have that on your list’ so we do a support together, to do clear overtaking.” (P5)</td>
</tr>
<tr>
<td>Opportunities &amp; Improvising</td>
<td>6</td>
<td>“Asking the other vessel for example 'oh I can see there’s another vessel and I can’t reduce now, is it possible for you to reduce to help me to overtake a little bit quicker or so’” (P2)</td>
</tr>
<tr>
<td>Self-monitoring</td>
<td>9</td>
<td>“what I have changed is that the reason for overtaking is to be faster... be defensive, safety first, if we are outside twenty minutes later no problem at all.” (P2)</td>
</tr>
<tr>
<td>Anomalies</td>
<td>5</td>
<td>“the vessels are not having the speed that they said before. For example a tanker said 'We do 12kn' and in reality they do only 10.” (P2)</td>
</tr>
<tr>
<td>Equipment Difficulties</td>
<td>6</td>
<td>“We had this on one vessel with the gyro compass failure, it was a big one really, more than ten degrees actually. We know the courses which we have to go and then normally you making on the autopilot is going, I made this course, make a tracking in this course and I saw something is wrong immediately, even didn't look at the equipment, only outside on the window, because with our experience we know where are the buoys and we know the direction of course, you have the leading lights and everything.” (P4)</td>
</tr>
</tbody>
</table>

4.4 Simulation Interviews

In the Simulation Interview (SI), each participant proceeded to walk the interviewer through the overtaking process step by step. Participants marked the positions of the model vessels and the speed requirements on the printed image and used them as placeholders as they were explaining in detail how the manoeuvre will be done (Fig. 3). An example of these walkthroughs is reflected in the following quote by Participant 2:

So this one is doing, let's say, 7 knots against the tide. One would do 15–16 in the waters of 13 knots, that is 7 knots faster. If I am seven cables behind it, and it looks very close, it looks like seven cables, so I can overtake her, in about 10 minutes. Six minutes to be at even, and another 4 minutes to be ahead of her.

During the walkthroughs, participants revealed how they collect and assess the essential and desirable information they need, how they perform their calculations by taking into account the hydrodynamic effects and various parameters and how situation assessment impacts a course of action. For example, when describing their approach to estimating the safe speed, Participant’s 1 response illustrated the blend of factors that influence their decision making and situation assessment by stating:

In other case without traffic I would go to slow already nearly here, but we have ebbtide, so the speed is coming down well, so these are around 5 miles to 6 miles to the harbour pilot and to the tugs which are waiting for me.

Besides determining the cognitive processes involved with the overtaking in the scenario, the purpose of the SI was to identify also potential errors that might challenge the safe outcome of the manoeuvre. The following events were discussed:

1. Course alteration of the ship being overtaken
2. Very strong unpredicted wind from southern direction
3. Fog patches that form suddenly and reduce visibility
4. Engine failure (vessel being overtaken)
5. Engine failure (own vessel)
6. Problems with the rudder (own vessel)
7. Problems with the rudder (vessel being overtaken)
8. Problems with the bow thruster (own vessel)
9. Misty weather
10. Uncooperative crew (vessel being overtaken)

For each event, participants explained how the situation will evolve, if the event will lead to an incident and what strategies they will follow to mitigate the danger. When asked what will happen if there is engine failure on the vessel they attempt to overtake when the manoeuvre is underway, Participant 3 said:

Disaster because she lost steering, you have to pass her in time. If she is going to the other side everything is safe for the overtaking, for the coaster not maybe. But she can drop the anchor. She will reduce the speed as well due to the ebbtide as well quite fast but maybe drift to the inner part.

From the previous list, events one to four are cases that were also included in the script prepared by the interviewer. They were all based on relevant regional accidents from the databases of the Federal Bureau of Maritime Casualty in Germany and were identified and assessed with experts during the domain familiarization phase. Appendix 1.3 includes the simulation interview prompts that were used during the SI phase.

4.5 Cognitive Demands Table

The CDT summarizes the final analysis of our study based on integrated data drawn across the OTD and KA products from experts, along with input from the Simulation Interviews. The table contains twelve high level cognitive challenges that occur throughout the phases of the overtaking manoeuvre:

1. Calculate the speed difference with the forward vessel
2. Determine if there is enough room to initiate overtaking
3. Estimate how the traffic situation will evolve
4. Communicate effectively with other ship and other actors
5. Combine information and cues from various sources
6. Collaborate with the other mariners (pilot, master, crew members)
7. Determine the effect of current
8. Determine the intensity of the hydrodynamic effects
9. Calculate duration of overtaking
10. Maintain a safe speed
11. Maintain a safe passing distance
12. Plan ahead

No major contradicting themes and examples were found across the sample. The cognitive challenges had common elements and should not be considered on their own, but rather as a whole, to provide a complete picture of cognitive challenges in overtaking. Prominent themes concerning the strategies employed by pilots in response to difficult cognitive challenges of their role included the utilization of tacit and experiential knowledge, and the consideration of the context they were in.

The final version of the CDT contains a total of 194 elements, including the 12 high level cognitive challenges, 69 items that show why these challenges are difficult, 51 common errors that can occur during the process of overtaking and 62 strategies and practices to deal with the challenges. In addition to the 194 elements, the last column in the CDT contains the cues and sources that are relevant to each cognitive challenge, as they have been expressed by participants during the interviews. Table 4 provides an excerpt of the CDT with elements for two cognitive challenges and Appendix 1.4 contains the complete data.
### Table 4
Extract from the Cognitive Demands Table for two cognitive challenges

<table>
<thead>
<tr>
<th>Cognitive challenge</th>
<th>Why difficult</th>
<th>Common errors</th>
<th>Strategies &amp; Practices</th>
<th>Cues &amp; Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Calculate the speed difference with the forward vessel</td>
<td>• Speed limits in fairway segments</td>
<td>• Speed difference less than 3-4kn and overtaking takes longer than anticipated</td>
<td>• Reliance on tacit knowledge – know how much speed difference is safe in these conditions</td>
<td>• Speed of both vessels</td>
</tr>
<tr>
<td></td>
<td>• Equipment and manoeuvring limitations</td>
<td>• Small ships are likely to be most affected by suction</td>
<td>• Change speed to achieve good speed difference</td>
<td>• Fairway status</td>
</tr>
<tr>
<td></td>
<td>• Environmental effects on speed (wind, current, tide)</td>
<td>• Passing with slow speed can be dangerous for either vessel</td>
<td>• Apply corrective helm</td>
<td>• Environmental conditions</td>
</tr>
<tr>
<td></td>
<td>• Involved vessels might need to slow down to use tugs</td>
<td></td>
<td></td>
<td>• Tide, current</td>
</tr>
<tr>
<td></td>
<td>• River seabed affects the speed</td>
<td></td>
<td></td>
<td>• Manoeuvrability characteristics</td>
</tr>
<tr>
<td></td>
<td>• Banking effects on speed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Not enough speed difference can cause suction</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Determine the intensity of the hydrodynamic effects</td>
<td>• Hydrodynamic interaction is noticeable in overtaking because of duration of passing</td>
<td>• Proceeding at full sea speed increases the risk of an uncontrolled shear</td>
<td>• Perform overtaking as fast as possible</td>
<td>• Under keel clearance, hull, draught, trim in relation to the displacement factor</td>
</tr>
<tr>
<td></td>
<td>• Changing the speed might result in course changes and loss of control for both vessels</td>
<td>• Inappropriate speed in relation to the depth of water might lead to loss of control</td>
<td>• Continuously monitor the status of overtaken vessel</td>
<td>• Available depth of navigable water</td>
</tr>
<tr>
<td></td>
<td>• Smaller vessels gain speed when overtaken by big vessels</td>
<td>• Fail to treat each manoeuvre as unique (different ships, conditions, and ship bridge crew (human factor))</td>
<td>• Reduce speed in good time</td>
<td>• Engine power, rudder</td>
</tr>
<tr>
<td></td>
<td>• The smaller vessel may change course towards the path of the large vessel (suction)</td>
<td>• Focus on speed difference and ignore the effect of a deep draft in the interaction</td>
<td>• Sufficient contingent power available to aid the rudder if necessary</td>
<td>• Type</td>
</tr>
<tr>
<td></td>
<td>• More critical when a smaller vessel is passing a larger vessel</td>
<td>• Hydrodynamic pressure zone around the vessel might extend further than assumed</td>
<td>• Maintain a safe speed and safe distance</td>
<td>• Loading condition of vessel</td>
</tr>
<tr>
<td></td>
<td>• Deep draught vessels have a slower response to speed reduction</td>
<td></td>
<td>• Cooperate closely with overtaken vessel</td>
<td>• Vessel has a list or is upright</td>
</tr>
<tr>
<td></td>
<td>• Possible trapping situation for overtaking vessel once it is past the VtO</td>
<td></td>
<td>• Navigate with leeway to avoid suction</td>
<td>• Speed of vessels</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Distance between vessels</td>
</tr>
</tbody>
</table>

#### 4.6 Communication

Figure 5 shows the information exchange between the pilot and the crew (master, officer on watch (OOW), helmsman) who form a bridge team. The dotted arrows depict the communication that may occur with other vessels if the pilot deems it necessary, as described in the TD. The pilot on board has a central role for the effective communication between the bridge team and the other parties, i.e., other vessels, the pilot on radar duty at the pilot company facilities and the VTS operator that oversees the traffic. Communication with all parties is done via a dedicated VHF channel. Pilots might contact other vessels before they initiate overtaking to communicate their intentions, get updated information and decide on a safe speed and passage. They might also seek for confirmation from other vessels, ensure that all parties are aware of the manoeuvre and proceed with safety. The pilot might contact
their colleague on radar duty to ask for assistance with a manoeuvre or to get an updated status assessment. The VTS operator oversees the traffic in the region, can give or withdraw consent for overtaking and might also offer assistance to all vessels. The VTS operator and pilot on radar duty may also initiate contact with the bridge team if they want to intervene for safety reasons.

5 Discussion

The present study aimed to identify the cognitive challenges of sea pilots during overtaking manoeuvres in restricted waterways. To reach our goal, we employed ACTA interviews in combination with findings from observations and related domain familiarization activities. Our approach helped us to systematically extract and sort out the critical tasks that pilots must carry-out during such manoeuvres and to investigate in depth the complexity of the whole procedure. Based on the content analysis of the interviews, we have identified twelve different cognitive challenges that are relevant to the safety and effectiveness of the overtaking manoeuvre. We have also described the tacit knowledge, strategies, common errors and experience aspects that are relative to the cognitive challenges.

All the participants interviewed throughout the studies agreed unanimously that the dominant goal of pilotage activity is to navigate with safety, to ensure the protection of the environment and to minimize the logistic costs. As one pilot pointed out during the domain familiarization phase, ‘Our part of the job is to see that’s it’s safe, that is economical and ecological - these three things we have to get matching’. In maritime traffic, ensuring the safety, guaranteeing fluency and promoting environmental protection can be considered to be the three basic tasks of pilotage (EMPA 2022; IMO 2022; IMPO 2022). SMEs in previous studies from other regions have also offered similar insights. According to Darbra et al. (2007) who investigated the basic tasks of pilotage in Australia and New Zealand, the most important task for pilots is to ensure safe navigation and environmental protection. Mansson et al. (2017) have also reported a consensus among maritime professionals in Australia that the dominant goal of the joint activity was to ensure the ship gets from one position to another, and that this should be achieved as efficiently as possible without compromising safety.

Does it make sense?

Overtaking, or giving extra space in a meeting situation, are considered deviations from the intended route of a vessel underway. The responses from the pilots in our study indicate that they will avoid overtaking other vessels in restricted fairways if there is any doubt that they will succeed in achieving the dominant goal of their job and if it doesn’t ‘make sense’ to them in the grand scheme of things. Pilots will prefer to stay behind another vessel when they are on an outbound ship instead of attempting overtaking, because initiating overtaking will require more effort and more time. They prefer to act in open sea, where there are fewer restrictions (fairway depth, width, speed limits) and the vessel characteristics will not be an important factor during passing manoeuvres. As one participant pointed out:

Usually you don’t do it because you keep in mind that on the distance you’re not losing too much time, that’s why it makes no sense to overtake but the thing is you’re losing only fifteen minutes, ten minutes on the whole way. But the interaction if you overtake the ship it takes too long time to see the traffic in advance, to see the situation in advance and the time where the effect is possible. Acting is much longer, much more than if you’re just passing shortly. A hard effect on a short time.

In comparison, when they are on board an incoming vessel, pilots might attempt overtaking to gain some time, because they have arrival deadlines that affect the schedules of tugs, harbour pilot and possibly other ships. Butler et al. (2022) suggested that financial pressures also influence pilots’ decisions during routine pilotage operations. Participants in this study, however, emphasized that they aim for balance and VTS will intervene if such a decision might block the flow of traffic in the region.

Decision Making skills

Pilots are experts who have gained their skills through training and practical experience and can recall specific patterns and specialized knowledge. As experts, pilots are able to restructure, reorganize, and refine their representation of knowledge, applying it more efficiently into their environment. (Orlandi and Brooks, 2018). Their decisions, such as whether to communicate with the other vessel or not, to estimate if the available space is enough for overtaking, and if their course is safe to mitigate the hydrodynamic effects are made by recognition of domain-specific patterns. Respective examples of such patterns are the experience of the crew in the other vessel, the width of the fairway, and the changes to the speed of both vessels during overtaking. These examples suggest that pilots frequently recognize the situation at hand and automatically select their actions. These findings align with results from Butler et al (2022) who applied CDM and showed that pilots decided by blending intuition and analysis, usually under time pressure and
conditions of uncertainty and dedicated most of their decision making efforts in diagnosing the situation by detecting anomalies or mismatches.

Further, our results strongly indicate that maritime navigation in general is not based on simple procedural if-then decision making activities, because it occurs within a complex sociotechnical system. Pilots treat every situation as unique, even if some or most aspects are the same, such as the crew, the ship, or even the weather and environmental conditions. *The danger for older pilots is always the routine. I did it thousand times before and then you may lose something*. Our participants emphasized that they have to consider *‘too many parameters*, of which many are dynamic, and that small changes in one of these parameters (i.e. speed, course, distance) can cost them a lot of resources or even destroy a manoeuvre. Thus, the decision-making actions need to be focused on the specificities of the situation at hand and not on a routine, because pilots might miss a cue or make a misjudgement leading to an incident or near miss. Although the piloting task may seem routine based on the significance that is attributed by the pilots on good preparation, the complexity of interactions between parameters makes it that one cannot resort to rule based decision making. This is evidenced by the common errors described by the study participants. Most point to ignoring or missing secondary parameters that may, nevertheless, significantly influence the evolution of the manoeuvre in certain circumstances.

**Experience**

All five participants emphasized how incidents that occurred within their first year of service as pilots have affected their decision making. They pointed out that they now think twice before attempting to perform any course deviations, based on their past experiences, and consider these early career events as shaping factors of their cautious attitude. *‘You get the odd situation in your career that (makes) you improve your job’*. Specifically, the case of overtaking a deep draft vessel with a small vessel is a typical “main mistake” that all participants have experienced either as pilots on duty or as witnesses to a related situation. They all stressed the dangers and difficulties of this particular manoeuvre, which is riskier than other cases of overtaking and can lead to loss of control. The criticality of such overtaking encounters in close proximity has been confirmed by several studies (Inoue 2000; Vantorre et al. 2017; Yuan et al. 2015; Zhou et al. 2023).

Performing overtaking requires continuous attention not only from the pilot but also from the other actors, primarily the person on the helm, the OOW, but also the people from the bridge teams of the other vessels involved in the manoeuvre. For every encounter, pilots need to assess the experience and capabilities of the other pilot/master in terms of judgment, decision making skills, navigation skills and exposure to difficult manoeuvres. Participants mentioned that, to attempt such critical manoeuvres, they first need to determine if their confidence to the pilot/master of the other vessel(s) is adequate. It has been also acknowledged by the participants that they will adjust their behaviour depending on which pilot is on board of the vessel that will be overtaken or a vessel that is sailing opposite or nearby when the manoeuvre occurs. A similar observation has been done by Brödje et al. (2010) regarding the local area knowledge aspects of VTS operators, who will modify their monitoring in accordance with which OOW or which pilot is onboard.

**Communication**

Responses from the participants of this study as well as data from our observations suggest certain situations where communication is necessary for the safe outcome of overtaking and smooth cooperation. For example, overtaking in fog conditions or during night will be initiated after radio contact with the other vessel and possible other mariners on board or on shore (radar pilot, VTS) to inform them of the upcoming course deviation. Communication can also be used to request cooperation and to resolve uncertainty. Communication can also be a tool for pilots to assist vessels that have limited experience of such manoeuvres in the local fairway conditions and usually sail without a pilot due to the regulations.

Our results further suggest that communication between the pilot, master, the crew on the bridge, VTS operators and radar pilot must be well organized and used with purpose and professional courtesy. The participants mentioned that excessive communication on the dedicated VHF channel or small talk on the bridge can distract mariners, especially inexperienced ones. Our findings align with results from a study on the SA of navigators by Sharma et al. (2019) where participants listed irrelevant communication and noise on radio channels as some of the factors that affect their SA during pilotage. Pilots need to inform about their intentions in a timely manner and pursue the cooperation of every other relevant actor. Undisciplined communication from any of the actors at the wrong moment can cognitively saturate the others with wrong or untimely information leading to a drop in their situation awareness and increasing the risk of an incident or accident. One notable example from our participants’ responses is when masters or colleagues on other vessels do not react at the calls of pilots, due to wrong VHF settings or other reasons. These situations of non-existent communication might lead
pilots to contact their target recipient via third parties (shore radar, VTS) or even to abort the overtaking manoeuvre completely to avoid the risk.

Deficient communication can also arise when crews use a language or slang that is not understood by the pilot, or when the conversation on the VHF is not clear. This was also evidenced in studies in Australia, where English proficiency was reportedly used as a basis for expectations regarding competency by pilots and VTS operators (Mansson et al. 2017) and could become a barrier for effective bridge resource management (Butlers et al. 2022). On the other hand, pilots in our study have mentioned that conversations in the same native language with colleagues from the pilot station work in their advantage, as was the case during the field trip where communication was done exclusively in German for some parts of the voyage, depending on the regulations of the pilot station responsible for the region we were sailing through. In this case, non-German speaking crew members will not be able to understand any communication that will be done in a language they are not familiar with. The use of different languages or agreements that are made in noncommon languages and not translated can increase risk (Nilsson 2017).

The lack of communication between vessels in close proximity can result in ambiguity and increase the likelihood of an incident (AMSA 2020). A characteristic accident that is attributed to “less than optimal” communication was the collision between the tanker Chembulk Houston and the container ship Monte Alegre on 2015 in the Houston ship channel, USA. According to the report, the pilot’s decision to increase speed on the Monte Alegre without informing the deputy pilot on the overtaking Chembulk Houston was the probable cause of the accident (National Transportation Safety Board, 2015). Recent studies have indicated that communication errors are the second most frequent type of errors in the piloting operations (Ernstsen and Nazir 2018) and have revealed the high percentage of human error due to failure in communication during navigation in narrow waters (Aydin et al. 2021; Sánchez-Beaskoetxea et al. 2021). Navas de Maya and Kurt (2020) have also suggested that inadequate communication is one of the most contributing factors to bulk carrier collision accidents. These results corroborate with our findings and highlight that piloting operations and navigation in restricted areas in general are dependent on efficient and precise sharing of information.

Despite the evidence that calls for efficient communication, it remains nonobligatory and contacting other mariners depends on the maritime professional. AMSA advise but do not oblige pilots to ‘give a courtesy call on VHF radio before the manoeuvre to confirm that the other vessel is aware of their intentions and to confirm that it is safe to proceed’ when manoeuvring in close proximity and/or overtaking other vessels in coastal pilotage areas (AMSA 2020). The participants of our studies have stressed in their responses that communication is optional when overtaking, even though ‘contacting other vessels’ is a step of the TD that they constructed (Fig. 3). Our findings are in line with the observation from Norros (2004) in her seminal study of piloting situations in Finland that communication of intentions was scarce as a prerequisite for sufficient monitoring despite the clear demand for it. Norros (ibid) further argued that because the piloting practice is nearly entirely tacit, communication and other forms or cooperation can be considered irrelevant, and even annoying. Similar indications that pilots focus on the uniqueness of each situation they face and do not follow if-then prescriptions in their decision making appear in our results. Therefore, the current piloting practice paradigm, where pilots do not rely on explicit procedure but anticipate the future course in the form of absorbed coping (Dreyfus 2001), could explain the communication habits of pilots.

Planning and Foresight

Our study highlights the importance of the preplanning phase, which the participants have aggregately deemed as the most cognitively challenging in overtaking. This is reflected in the TD, where four steps demonstrate the importance of preparation for pilots in deciding whether to overtake or not, and in the CDT, where all twelve cognitive challenges resonate with preplanning. These findings are consistent with previous studies where pilots have confirmed that preparation and management help to create extra safety margins (Mikkers et al. 2012) and overemphasize how crucial is the planning process in piloting (Sharma et al 2019).

Mariners need to foresee how the traffic situation might develop after an overtaking manoeuvre is complete. For example, when they sail inbound with a cargo vessel that is approaching the port for docking, they know that its speed must be 6kn maximum so that the tugboats can escort it. Pilots need to consider possible future situational or operational demands (speed limits, destination of involved vessels, opposite traffic, blocked terminal, etc.) before initiating an overtaking; ‘I should calculate really in my head, that's very important for the inbound traffic, because let's say a big vessel is coming’. Even when the pilots consider the conditions for overtaking to be satisfied, the aftermath of the manoeuvre might disturb the traffic and jeopardize the overall goal. A pilot ‘is always not driving where he is driving, we are always with our mind more ahead’ to be clear of the dangers and demands of any situation and create future safety margins. When the overtaking is complete, a new situation is at play.
The findings also indicate the level of strategic thinking that pilots demonstrate in a maritime traffic system. Experienced maritime navigators such as pilots perceive the affordances and constraints not only for their own actions, but also for the joint human–technology system (Øvergård et al. 2010). Within the boundaries of this system, pilots assess how much they can trust the people and the information that is available to them, especially in case they intend to perform a critical manoeuvre. Pilots frequently rely on their own subjective judgment to estimate what will happen in the next five to thirty minutes during a manoeuvre preparation, because of delays in the bridge systems update rate, which the use of a PPU can compensate for up to an extent (de Vries 2017). Our findings extend this argument by providing evidence that pilots frequently verify the cues they receive with input from other sources and from the continuous monitoring of their surroundings with eyes and binoculars. ‘We always see the overall control, that is one of our big points. Keep over everything on the bridge, keep the bridge under control, check the traffic all the time, look out of the window, and not always on the radar screen, keep ears and mind and eyes wide open then you are safe in your job.’

Cognitive challenges and Situation Awareness

The ability to calculate the speed difference and foresee how intense the hydrodynamic effects will be on overtaking, as well as the majority of the cognitive challenges identified, are closely related to the situation awareness concept proposed by Endsley (1995). This supports previous research suggesting that building and maintaining situation awareness is one of the driving factors in the decision-making process in pilotage and navigation in general (Chauvin et al. 2013; Cordon et al. 2017; Hockey et al. 2003; Øvergård et al. 2015). In our case, the pilot’s situation awareness is crucial for managing information from different sources and planning the flow of actions before, during and after the overtaking manoeuvre without compromising safety (Endsley 2012, 1995).

Pilots also need to verify the necessary information and cues before initiating the manoeuvre and get the latest updates as the manoeuvre progresses. The use of the PPU has contributed positively to supporting the SA demands of pilots we have interviewed. They try to use it in the preplanning phase and when on board, they use it to verify and get the latest updated ship information. ‘I try to check it before I start the voyage. Depends on the ship, plugging in to the ship system I know I have AIS plugged for example and then we have the ship data, no separate data so you shouldn’t trust that, better check first.’

Pilotage may have varied SA information demands and it is crucial that, when the demands reach a peak, such as during an overtaking manoeuvre, they are adequately supported for the pilots as well as for the rest of the actors involved. Preplanning was found to be the most cognitively demanding phase while execution of the manoeuvre, although critical, was found to be less demanding as in this phase pilots mainly monitor that everything goes well. Our CDT analysis shows that the interpretation of the cues and state of elements as well as anticipation of the status of other vessels, the environment, and weather, are prominent aspects of the decision-making process and directly associated with the comprehension and projection levels of SA (Endsley 1995). Similar observations have been made by Chauvin et al. (2008). Further, our analysis implies that when the objective is to overtake another vessel, the pilot focuses only on specific elements, part of their state and their relation to other elements.

The SA of the pilots can be undermined by lack of information. Pilots may often be unaware that certain equipment and systems are functioning at less than 100% (i.e. bow thruster, propeller, rudder, etc.), which can cause problems in the execution of their passage plan. Also, there are some factors deriving from the limitations of the human mind and the features of the technical systems that they use during pilotage, the so-called Demons of Situation Awareness (Endsley and Jones 2011). Using the SA demons characterization, we have reviewed our findings for causes for SA failure in pilotage. Some examples are:

- Attentional Tunnelling: Excessive focus on certain instruments
- Errant Mental Models: Possible confusion over a cue, misinterpretation of a signal (can also refer to the demons of Misplaced Salience or Complexity creep)
- Workload: less attention to observing surroundings, neglect cross checking of cues and peripheral information
- Data Overload: unnecessary communication from VHF

A characteristic example of SA demons is associated with an incident that occurred at the beginning of the pilotage career of one participant. The pilot explained how he confused a dredger with a vessel by misinterpreting a light signal due to low visibility and weather conditions. ‘I stopped my overtaking cause I thought this is a lighted stem part of a vessel, but that was wrong. That was just a dredger.’

5.1 Practical Implications
Information about cognitive challenges derived through ACTA can inform design specifications of the workplace and operating procedures. For instance, understanding the connection between Under Keel Clearance (UKC) all the way to the pilot's projection of how intense the hydrodynamic effects will be, can provide insight into the design of PPUs and other bridge instruments. The CDT provides the input needed to determine which information is required for supporting the task of overtaking. Information needed together should be co-located and organised in a way that reduces or eliminates the need for mental calculations, e.g., by being graphically configured in a way that directly answers the main decisions related to the task, using the principles of Ecological Interface Design.

The integration of the PPU screen on board to share pilot's passage plan with the crew could improve the congruency and the faster update rate of information. Also, sharing the passage plan with other vessels and shore can improve communication, where local knowledge can contribute to safety, without the deficiencies of oral communication. This implication aligns with the suggestion by Rønningen and Øvergård (2017) that sharing the pilot passage plan represented in the PPU on the ECDIS monitor may have positive effects on the ability to identify and correct navigational errors by the pilot or other bridge crew members regardless of the current pilotage paradigm. One could argue that a shift in the pilotage paradigm towards a less pilot centric culture in operations and decision-making aspects will improve safety.

Particularly interesting were the results in relation to training. For instance, novice pilots are likely to rely too much on instruments or visual cues to obtain SA. Therefore, pilot trainees should be made aware of how foresight, local knowledge, and good communication can contribute to improving their SA and making decisions with reduced risk.

Also, cognitive aspects of decision making in pilotage navigation and their relation to SA as discussed in this paper may help to better describe and understand maritime pilotage accidents or incidents.

An advantage of the ACTA methodology is that it provided us with a structured way to gather and organize a large amount of diverse data. Creating the task diagram, knowledge audit table, and CDT helped us to synthesize the content of each into the major challenges. Because the CDT presents the major findings in a concise way, it can be a useful communication tool for system designers to develop more user-centred solutions. Indeed, designers often fail to fully appreciate the cognitive and operational demands placed on the end-users of more and more complex maritime instrumentation since there has been apparently no systematic and sustained tradition of involving users in their design (Grech and Lemon 2015).

5.2 Limitations

The ACTA interviews proved to be a valuable method for the scope of our study, as they provided in-depth insights of pilots’ decision-making activities during overtaking. Nevertheless, some limitations of our study should be mentioned. First, all participants for domain familiarization and ACTA interviews were recruited from the same pilot station in Bremerhaven, Germany. Pilots were all male Germans, with homogenous professional, cultural, and national backgrounds. This could be one of the reasons why no major contradicting descriptions of cognitive challenges were found among participants. It is also a challenge to the generalizability of our study, since its findings are generated from participants whose decision making is already framed by the organisational constraints of this station and national pilotage regulations not fully taking into account the multicultural and multinational nature of contemporary maritime operations. Therefore the findings can be of greater value for implementation at the area of Outer Weser. A possible expansion of the sample to include participants from different pilot stations from the German Bight and other ports in the North Sea may yield more generalizable results.

Second, there is the issue of confidentiality regarding the collection of data on incidents and accidents, which are considered sensitive topics. Some participants declared that they were not allowed to speak about certain matters, based on professional agreements that impose restrictions for sharing organizational information with outsiders. Therefore, it is possible that some aspects or certain experiences were not shared with us. Third, the data collection was generated in a non-operational environment, which is a limitation to the ecological validity of the data. Pilots relied on their retrospective memory and explicit knowledge to describe the manoeuvre. This could also introduce a recollection bias of cognitive challenges related to implicit knowledge. It is evident that direct observations of such manoeuvres would yield more reliable data, but such opportunities are hard to come by, due to operational and safety constraints. Lastly, the time constraints and the use of English from non-native speakers might also have affected the quality of gathered data.

6 Conclusions
The results of this study make a contribution to the literature through the investigation of the cognitive challenges of pilots during critical manoeuvres supporting previous research findings on decision-making expertise in pilotage and maritime navigation in restricted waterways. Our findings strengthen the argument that the dominant goal of pilotage is to ensure the safety of navigation. Overtaking is a deviation from the planned route of a vessel and pilots will avoid spending resources to attempt it in restricted waterways. Nevertheless, focusing on such a manoeuvre helps uncover the most demanding parts of the pilots’ job, since it is one of the most common and complicated encounters between vessels.

The study results suggest that even though the piloting task may appear as routine, the complexity of relationships between parameters and the dynamic evolution of each manoeuvre prevents experienced pilots from relying on rule-based decision making. The preparation for such a manoeuvre was found to be the most cognitive challenging phase, during which pilots need to combine heterogeneous parameters and verify cues from various sources anticipating at the same time the possible future situational and operational demands. The results also highlight how effective communication between the pilot and other mariners requires careful planning, deliberate use and professional courtesy to clear doubts and maintain safety, even if this communication remains optional.

Future research efforts on the subject include the organization of workshops with pilots to investigate the co-dependency between information elements and factors that pilots take into consideration to assess a situation.

**Declarations**

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**Data availability statement**

The texts from the transcribed interviews that were generated and analysed during the current study are not publicly available due to data privacy laws but are available from the corresponding author on reasonable request.

**References**

Figures

Figure 1

The area of the outbound first voyage (blue line) and the inbound second voyage (red line) in the Jade–Weser estuary. Adapted from “Übersichtskarte Jade- und Wesermündung” by Alexrk, used under CC BY-SA 3.0.
Figure 2

Research framework and methods
Figure 3

Overview Task Diagram illustrating the stages associated with pilots' decision making when overtaking in a fairway.
Figure 4

A participant demonstrates how and when will the overtaking occur in the specific scenario with the help of the low-fidelity simulation material.
Figure 5

Information exchange before and during overtaking based on the scenario used in the simulation interview

**Supplementary Files**

This is a list of supplementary files associated with this preprint. Click to download.

- Appendices.pdf
- Appendix1.4.pdf