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Improving situation awareness during safety-critical navigation: A study on cognitive challenges and factors affecting decision-making of maritime pilots

Doctoral Thesis

by

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Αφιερωμένη στους αγαπημένους μου γονείς Γιάννη και Μαρία
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List of Abbreviations

Automatic Identification System (AIS)

Analytic Hierarchy Process (AHP)

Applied Cognitive Task Analysis (ACTA)

Automatic Identification System (AIS)

Bayesian networks (BNs)

Bridge Resource Management (BRM)

Cognitive Demands Table (CDT)

Cognitive Map (CM)

Cognitive Task Analysis (CTA)

Critical Decision Method (CDM)

Decision Making Trial and Evaluation Laboratory (DEMATEL)

Dynamic Positioning System (DPS)

Electronic Chart And Display Information System (ECDIS)

Electro-Oculography(EOG)

Engine Resource Management (ERM)

Estimated Time of Arrival (ETA)

Fuzzy Cognitive Map (FCM)

German Federal Bureau of Maritime Casualty Investigation (Bundesstelle für Seeunfalluntersuchung -BSU)

Global Positioning System (GPS)

Goal-Directed Task Analysis (GDTA)

Human Factors Analysis and Classification System (HFACS)

Hydrodynamic interaction (HI)

Integrated Bridge System (IBS)

International Maritime Organization (IMO)

Knowledge Audit (KA)

Multi-Function Displays (MFD)

Officer On Watch (OOW)

Participatory modeling (PM)

Portable Pilot Unit (PPU)

Radio Detection and Ranging (RADAR)

Recognition-Primed Decision (RPD)

Ship to Ship Interaction – S2S Interaction

Simulation Interview (SI)

Situation Awareness (SA)

Subject Matter Experts (SMEs)

Tanker Motor Vessel (TMV)

Task Diagram (TD)

Vessel to Overtake (VtO)

Vessel Traffic Service (VTS)

Vessel Traffic Service operators (VTSOs)

Workshop (WS)

Abstract

Modern navigation is an inherently complex cognitive process that requires mariners to process an increasing amount of information while performing navigational tasks. Within confined waters, the ship bridge crew collaborate with maritime pilots, experienced master mariners familiar with local waters, to ensure safe vessel passage. In these waterways, overtaking situations are frequent, requiring precise, rapid manoeuvres often under operational and time pressure. Approximately 90% of marine accidents are reported in confined waterways and are frequently linked to poor decision-making, often caused by a lack of situation awareness. Despite the technological advances in the design of navigational assistance systems and the automation of many procedures, navigation errors still occur, due to misinterpretations or misunderstandings of the signals provided by technological aids and nearly no automation support is available for complex manoeuvres such as overtaking.

To design systems supporting safe navigation in demanding and critical manoeuvres, it is crucial to understand the dynamic and complex work domain of sea pilotage. This thesis contributes to the field of maritime pilotage by investigating in depth the pilots' decision-making processes during overtaking manoeuvres in restricted fairways. The thesis systematically explores the cognitive elements that influence the decision making and situation awareness of maritime pilots during overtaking. Lastly, the research presents a cognitive model of the factors that marine pilots consider during their decision-making process and the way these factors affect safe overtaking.

The thesis consists of three studies. The first study comprehensively investigated maritime pilots' work activities through a series of training sessions, open structured interviews with expert mariners, review of accidents and field observations on board of cargo vessels. The focus of the research activities was to obtain familiarization with various types of ship bridge environments and manoeuvring, and to develop ethnographic interpretations of experience and work. The results contribute to expanding the knowledge on the pilots' goals, values, motivations and beliefs, their competencies, how their work is affected by organisational, operational, and environmental aspects, and how pilotage is integrated in the larger work setting of ship navigation. The findings provided a foundation for a case study on overtaking in the Bremerhaven port region in Germany, that facilitated the subsequent two studies.

The aim of the second study was to obtain a detailed description of the overtaking manoeuvre and to understand the cognitive processes of mariners when they perform this task in the fairway of the Bremerhaven port region. To achieve this, a qualitative study was designed using an adaptation of Applied Cognitive Task Analysis (ACTA) to interview five highly experienced sea pilots in northern Germany. The ACTA identified six phases of the overtaking task and twelve high level cognitive challenges affecting pilots' decision making and situation awareness. The main contribution of this study is a Cognitive Demands Table that summarizes these findings, including challenges, errors, strategies, and cues.

The third study sought to assess and model the factors influencing the pilots in their decision to overtake with safety. Using the same case study, scenario simulation interviews and Fuzzy Cognitive Mapping (FCM) techniques with four expert pilots were applied to understand the concepts and decision criteria and how they contribute to safe overtaking. The results revealed the significant influence of environmental, ship-related, traffic, human, and organizational factors, along with their intricate interconnections, and how these affect pilots in their decision for safe overtaking. The final FCM and the findings were assessed and validated in a final workshop with three expert sea pilots.

Overall, this thesis provided valuable insights into decision-making, expertise in pilotage, ship bridge systems design, operational procedures, and pilot training. Additionally, the findings contributed to the development of the FCM model that may be used to guide future research on human factors in pilotage, automation support and reduction of cognitive load during critical manoeuvres.

Keywords: decision making; knowledge acquisition; safety-critical systems; maritime navigation; cognitive task analysis; situation awareness; fuzzy cognitive maps; human factors; ergonomics.

Περίληψη

Η σύγχρονη ναυσιπλοΐα είναι μια εγγενώς πολύπλοκη γνωστική διαδικασία που απαιτεί από τους ναυτικούς να επεξεργάζονται έναν αυξανόμενο όγκο πληροφοριών κατά την εκτέλεση των καθηκόντων τους. Κατά την πλεύση σε περιορισμένα ύδατα (confined waters), το πλήρωμα της γέφυρας του πλοίου συνεργάζεται με πλοηγούς (maritime pilots). Οι πλοηγοί είναι πλοίαρχοι με εξειδικευμένη εμπειρία και γνώσεις συγκεκριμένης θαλάσσιας περιοχής, και υποστηρίζουν την ασφαλή διέλευση ενός πλοίου, όπου επιβάλλεται από τους κανονισμούς. Σε αυτές τις υδάτινες οδούς, οι ελιγμοί προσπέρασης (overtaking manoeuvres) απαιτούν κινήσεις με ακρίβεια και συμβαίνουν συχνά, συνήθως υπό συνθήκες πίεσης χρόνου και επιχειρησιακών απαιτήσεων.

Περίπου το 90% των θαλάσσιων ατυχημάτων καταγράφονται σε περιορισμένα ύδατα και είναι συχνά συνέπεια κακής λήψης αποφάσεων, η οποία πολλές φορές οφείλεται στην ανεπαρκή επίγνωση κατάστασης (situation awareness). Παρά τις τεχνολογικές εξελίξεις στον σχεδιασμό των συστημάτων υποστήριξης ναυσιπλοΐας (navigational assistance systems) και την αυτοματοποίηση πολλών διαδικασιών, τα σφάλματα πλοήγησης εξακολουθούν να συμβαίνουν, λόγω παρερμηνειών ή παρανοήσεων των σημάτων που παρέχονται από τεχνολογικά βοηθήματα. Επιπλέον, η υποστήριξη από αυτοματισμούς στα συστήματα της γέφυρας πλοίου για πολύπλοκους ελιγμούς όπως η προσπέραση είναι σπάνια και ελλιπής.

Για να σχεδιάσουμε συστήματα που υποστηρίζουν την ασφαλή πλοήγηση σε απαιτητικούς και κρίσιμους για την ασφάλεια ελιγμούς, είναι σημαντικό να κατανοήσουμε το δυναμικό και πολύπλοκο τομέα εργασίας της θαλάσσιας πλοήγησης (sea pilotage). Η παρούσα διατριβή συνεισφέρει στο πεδίο γνώσεων για τη θαλάσσια πλοήγηση διερευνώντας σε βάθος τις διαδικασίες λήψης αποφάσεων των πλοηγών κατά τη διάρκεια ελιγμών προσπέρασης σε περιορισμένα ύδατα. Η διατριβή διερευνά με συστηματικό τρόπο τα γνωστικά στοιχεία που επηρεάζουν τη λήψη αποφάσεων και την επίγνωση της κατάστασης των πλοηγών κατά την προσπέραση. Τέλος, η έρευνα παρουσιάζει ένα γνωστικό μοντέλο (cognitive model) των παραγόντων που λαμβάνουν υπόψη οι πλοηγοί κατά τη διαδικασία λήψης αποφάσεων και τον τρόπο με τον οποίο αυτοί οι παράγοντες επηρεάζουν την ασφαλή προσπέραση.

Η διατριβή αποτελείται από τρεις μελέτες. Η πρώτη μελέτη διερεύνησε διεξοδικά τα εργασιακά καθήκοντα των πλοηγών μέσω της παρακολούθησης εκπαιδευτικών σεμιναρίων για ελιγμούς, της ανασκόπησης αναφορών από ναυτικά ατυχήματα και της διενέργειας ημι-δομημένων συνεντεύξεων με έμπειρους ναυτικούς. Επιπλέον, πραγματοποιήθηκαν συστηματικές συμμετοχικές παρατηρήσεις πεδίου σε γέφυρες πλοίων εμπορικών πλοίων. Στόχος της μελέτης ήταν η καταγραφή των διαδικασιών και στοιχείων από το σύστημα εργασίας της γέφυρας του πλοίου και η ανάπτυξη εθνογραφικών ερμηνειών της εμπειρίας και της δραστηριότητας της πλοήγησης. Τα αποτελέσματα συνεισφέρουν στην επέκταση της γνώσης σχετικά με τον πώς η πλοήγηση ενσωματώνεται στο ευρύτερο πλαίσιο της ναυσιπλοΐας και τον τρόπο που η εργασία τους επηρεάζεται από οργανωτικές, επιχειρησιακές και περιβαλλοντικές πτυχές. Με βάση τα ευρήματα, δημιουργήθηκε μια μελέτη περίπτωση (case study) για τον ελιγμό της προσπέρασης στην περιοχή του διαύλου του λιμανιού στο Bremerhaven της Γερμανίας, που αποτέλεσε ένα πλαίσιο για τις δύο επόμενες μελέτες.

Στα πλαίσια της μελέτης περίπτωσης, η δεύτερη μελέτη αποσκοπούσε στην λεπτομερή περιγραφή και κατανόηση των γνωστικών διεργασιών των πλοηγών κατά την εκτέλεση του ελιγμού στην περιοχή του Bremerhaven. Η μελέτη χρησιμοποίησε μια προσαρμογή της Applied Cognitive Task Analysis (ACTA), μιας τεχνικής γνωστικής ανάλυσης εργασίας, για το σχεδιασμό και την πραγματοποίηση συνεντεύξεων με πέντε έμπειρους πιλότους στη βόρεια Γερμανία. Με βάση την ανάλυση ACTA, περιγράφονται έξι φάσεις του ελιγμού της προσπέρασης και δώδεκα γνωστικές προκλήσεις που επηρεάζουν τη λήψη αποφάσεων και την επίγνωση της κατάστασης των πλοηγών. Η κύρια συμβολή αυτής της μελέτης είναι ένας Πίνακας Γνωστικών Απαιτήσεων (Cognitive Demands Table) που συνοψίζει όλα τα ευρήματα, συμπεριλαμβανομένων των προκλήσεων, των λαθών, των στρατηγικών και των ενδείξεων που προκύπτουν από την ανάλυση των συνεντεύξεων.

Η τρίτη μελέτη είχε ως στόχο να διερευνήσει και να μοντελοποιήσει τους παράγοντες που επηρεάζουν τους πλοηγούς στην απόφασή τους να προσπεράσουν με ασφάλεια. Χρησιμοποιώντας την ίδια μελέτη περίπτωσης, πραγματοποιήθηκαν δύο εργαστήρια με τέσσερις πλοηγούς, όπου διενεργήθηκαν συνεντεύξεις και σχεδιάστηκαν γνωστικά δίκτυα (cognitive maps) από τους συμμετέχοντες με βάση την μεθοδολογία Ασαφών Γνωστικών Δικτύων (Fuzzy Cognitive Mapping, FCM). Το ενιαίο FCM μοντέλο που προέκυψε περιλαμβάνει τους παράγοντες (περιβάλλον, πλοίο, κυκλοφορία, άνθρωποι και οργάνωση της εργασίας), τις περίπλοκες διασυνδέσεις και το βαθμό επίδρασης τους στην απόφαση των πλοηγών για ασφαλή προσπέραση. Το FCM και τα σχετικά ευρήματα αξιολογήθηκαν και επικυρώθηκαν σε ένα εργαστήριο με τρεις έμπειρους πλοηγούς.

Συνοψίζοντας, η διατριβή συνεισφέρει πολύτιμες γνώσεις σχετικά με τη λήψη αποφάσεων, την εξειδίκευση στην πλοήγηση, το σχεδιασμό των οργάνων της γέφυρας του πλοίου, τις επιχειρησιακές διαδικασίες και την εκπαίδευση των πλοηγών. Επιπλέον, τα ευρήματα από τις μελέτες συνέβαλαν συνδυαστικά και στην ανάπτυξη του FCM μοντέλου που μπορεί να αξιοποιηθεί για να καθοδηγήσει τη μελλοντική έρευνα σχετικά με τους ανθρώπινους παράγοντες στην πλοήγηση, την υποστήριξη αυτοματισμού και την μείωση του νοητικού φόρτου εργασίας κατά τους κρίσιμους ελιγμούς.

Chapter 1 Introduction

This chapter initially presents an overview of the research domain within which this thesis is situated. It then outlines the rationale behind the research undertaking, followed by the formulation of the primary research goals and objectives. Four broad research questions are defined to guide the investigation, and the chapter concludes by providing a concise outline of the structure of the thesis.

1.1 Introduction

In the early morning of 5 April 2011, the Tanker Motor Vessel (TMV) ZAPADNYY and the TMV RHONESTERN departed from the port of Bremen and proceeded on the river Weser in good visibility, calm weather, and moderate traffic volume. Both vessels were navigated by their master with pilot advice and steered by a helmsman towards the North Sea. At around 8 o'clock, the stern of the RHONESTERN passed the superstructure of the ZAPADNYY in the exit of the bend at Vegesack during an overtaking manoeuvre. A few minutes later, ZAPADNYY collided with the front end of a floating dock of a shipyard, which was firmly moored on the northern bank of the river Weser (Fig 1, 2). ZAPADNYY had consented to participate in the overtaking manoeuvre and did not reduce speed for safety reasons. Moreover, the RHONESTERN was not aware of the difficult steerability of the low motorized ZAPADNYY that was most likely impacted by the hydrodynamic effects. None of the preventing actions taken by the crew helped ZAPADNYY to respond noticeably or to prevent her from straying towards the floating dock at the northern bank. The published investigation report 102/11 that was issued by the German Federal Bureau of Maritime Casualty Investigation (Bundesstelle für Seeunfalluntersuchung -BSU) stated that *"it is impossible to make a statement with sufficient certainty as to whether a decision to increase or reduce speed after the onset of a hydrodynamic effect in this single case under consideration, would in fact have had limited the impact of the accident"* (BSU 2012).

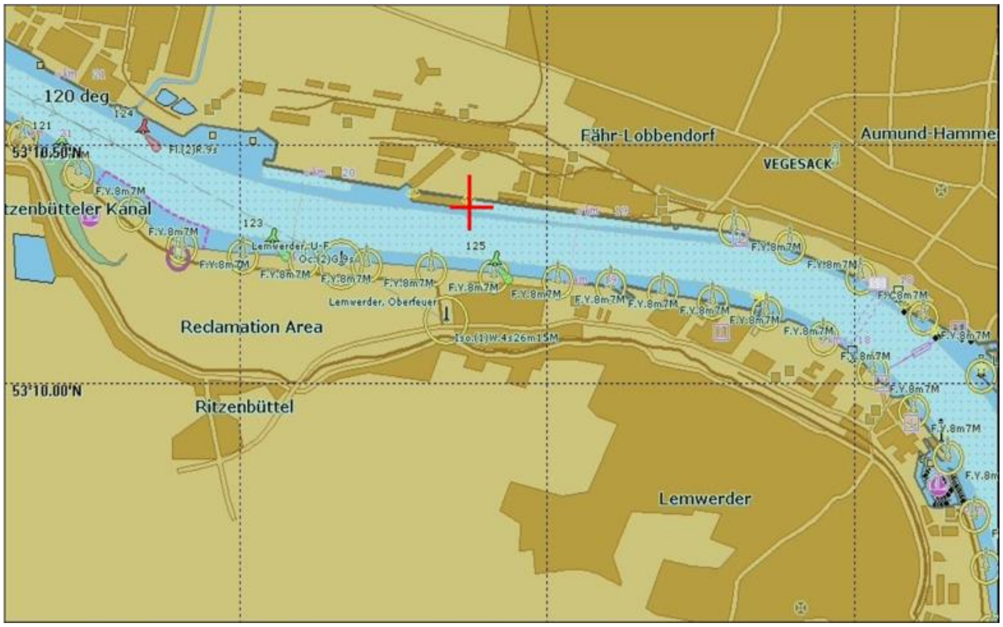


Figure 1: Section from the ENC DE 521650 Ed 2.0, Federal Maritime and Hydrographic Agency that shows the location of the collision between the TMV ZAPADNYY and a moored floating dock on River Weser off Bremen-Vegesack (BSU 2012)

Figure 2: Front end of floating dock wedged into forecastle of the ZAPADNYY. A tug boat is depicted during the effort to release the ZAPADNYY from the dock (BSU, 2012).

This incident illustrates that 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 (Hutchins; Hockey et al. 2003; Prison et al. 2013; Patriarca and Bergström 2017; 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; Wild 2011; Rønningen and Øvergård 2017). If these effects exceed a certain level, they can cause errors in manoeuvring which can lead to marine accidents like collision and grounding (Lee and Lee 2008; Prison et al. 2013; Du et al. 2018; Chakrabarty 2021).

About 90% of all marine accidents happen in confined waters such as channels and inshore traffic zones (Cockroft 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 (National Research Council 1994; Andresen et al. 2007; Darbra et al. 2007). 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 (Wagenaar and Groeneweg 1987; Chauvin and Lardjane 2008; Uʇurlu et al. 2015; Graziano et al. 2016) 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 (Øvergård et al. 2015; Cordon et al. 2017). 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).

1.2 Context

While technological innovations aim to mitigate the difficulties of decision making in navigation, 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 (Leveson 2011). Therefore, as suggested by Lützhöft and Dekker, 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 (Lützhöft and Dekker 2002).

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 pilotage 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 Goal-Directed Task Analysis (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 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.

In this context, the successful design of a system that is intended for use in the safety critical domain of maritime navigation, requires first a detailed, multi-faceted understanding of how the work is done, how navigators interact, how tools are used, what the mariners need for cognitive support, what policies are in place (Lazar et al. 2010). Further, it is also needed to inquire and explore how mariners perceive and assess a specific situation, what decisions they make and what aspects of implicit knowledge are needed.

1.3 Aims and Objectives

The main objectives of this research are:

- To contribute to the body of knowledge in the work domain of maritime pilotage by examining and describing the decision-making processes of pilots in demanding manoeuvring tasks within confined fairways, such as overtaking another vessel.
- To investigate and represent in a systematic way the cognitive aspects that affect the maritime pilots' decision making and situation awareness during overtaking.
- To develop a cognitive model by investigating the factors that influence the maritime pilots' decision making consider during their decision-making process and how these factors affect safe overtaking.

By making the tacit knowledge of safe overtaking from individual pilots explicit to themselves and each other, it is possible to enhance future workplace designs and operational protocols. This, in turn, can lead to better decision-making and ultimately reduce the occurrence of maritime accidents.

1.4 Research Questions

Four main research questions (RQ) have been identified that were used to guide the research for this thesis:

1. RQ1: While navigating in confined waters, how do maritime pilots decide to perform an overtaking manoeuvre?
2. RQ2: What are the cognitive processes of maritime pilots during an overtaking manoeuvre?
3. RQ3: What are the cognitive challenges that maritime pilots face when they decide to perform overtaking with safety?
4. RQ4: What factors do pilots identify as influencing their decision-making process towards safe overtaking?

1.5 Thesis Outline

The thesis is organised as follows:

The Introduction in **Chapter 1** describes the research context the justification, the aims and objectives of the thesis and the research questions.

Chapter 2 contains a a broad and comprehensive literature review that formulates the background of this thesis. First, the surrounding literature of ship manoeuvring, maritime pilotage, hydrodynamic interaction in relation to overtaking situations are presented. Then, the systems that are on the ship bridge are described, along with related images. A review of the pivotal role of decision-making in maritime follows, and the chapter concludes with an overview of human error and situation awareness in maritime.

In **Chapter 3**, the methodological approaches that were used in the second and third study are described. First, the Applied Cognitive Task (ACTA) analysis is presented, along with related applications and its comparison to other approaches. Second, the definition and properties of the Fuzzy Cognitive Maps (FCM) approach are described. The chapter concludes with a review on applications of FCM in human factors – ergonomics domain.

In **Chapter 4**, the domain familiarization and ACTA studies are presented. The chapter describes in detail the research design, the procedure, the results and discusses the outcomes, limitations, and practical implications of the two studies respectively.

Chapter 5 describes the methodological approach, procedure, and results of the FCM study. It also includes the validation process that was followed, and the structural analysis of the FCM. Further, the discussion of the results, the scenario analysis potential of the FCM and the overall limitations and practical implications are discussed.

Finally, **Chapter 6** presents the overall conclusions of this thesis and its contributions, and the suggested directions for future research.

Chapter 2 Background

2.1 Manoeuvring

A sea journey starts when a ship departs the harbour and sails through the archipelago in regulated fairways until it reaches the open sea. A regular voyage can be divided in three phases that require different levels of control depending on the complexity of the situation (Prison et al. 2013):

1. The close manoeuvring phase, i.e. navigating in very constricted areas such as harbours.
5. The archipelago phase, that refers to navigating into and out from the harbour before reaching the open sea, often through fairways, islands, and other denser traffic.
6. The open sea where there is less traffic and fewer or no geographic restrictions.

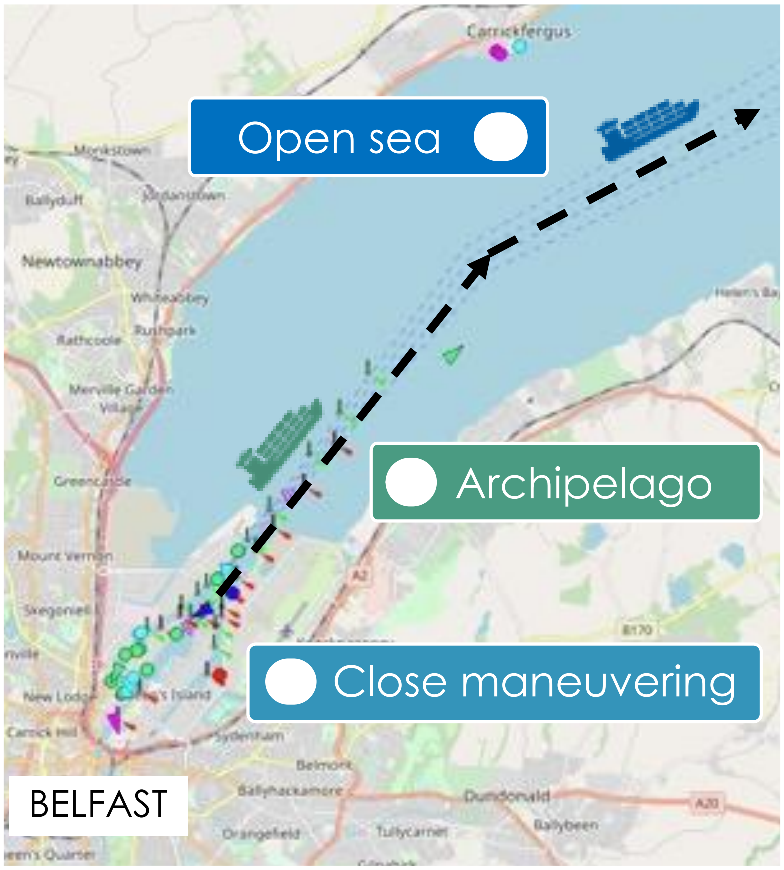


Figure 3 The phases of a sea voyage in the port of Belfast

Manoeuvres can be classified into two types: normal manoeuvring and manoeuvring in safety-critical and emergency scenarios (Baldauf et al. 2011). This classification can be expanded by considering diverse sea regions where manoeuvres must be done, such as open seas, coastal waterways and fairways, and harbour approaches and basins. Routine open-sea manoeuvring pertains to ship handling under normal circumstances, such as following a planned route from the port of departure to the port of arrival. Simple course modifications, speed adjustments based on the voyage plan, and so on are examples of such manoeuvres.

Manoeuvring in coastal areas, port entrances, and harbour basins includes manoeuvres such as embarking and disembarking a pilot, passing fairways and channels. It can also refer to berthing manoeuvres with or without tug assistance. Manoeuvring in safety-critical and emergency situations is concerned with operational risk management. It may include collision avoidance manoeuvres, manoeuvres to avoid grounding or dangerous rolling in heavy seas or to manoeuvre in the event of an accident, such as return manoeuvres in the case of a person overboard accident, and even search and rescue operations (Baldauf et al. 2011).

Items of the manoeuvring equipment may be rudders, fixed fins, jet thrusters, propellers, adjustable ducts for propellers, steering nozzles and waterjets (Bertram 2012). The rudder is a device to change direction ship by changing the direction of fluid flow that results in changes of ship direction. The steering wheel is placed at the threshold of the back hull (stern). The propeller is driven mechanically or hydraulically from the bridge by moving steering wheel (Hasbullah et al. 2019).

2.2 Pilotage and manoeuvring

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 (International Maritime Organization 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 - International Maritime Pilots' Association 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 (Andresen 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 - European Maritime Pilots' Association 2011). 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).

2.3 Hydrodynamic Interaction in overtaking

Hydrodynamic interaction (HI) has resulted in maritime casualties and dangerous incidents, particularly during overtaking operations. A vessel's motion creates an increase in water pressure at the bow and stern and a decrease in pressure amidships. HI occurs when the typical flow of water around the hull is constrained by another influence. Specifically, when a vessel comes too close to the bank of a channel or river (Bank Effect), too close to the seabed or riverbed (Squat), or too close to another ship (Ship to Ship Interaction – S2S Interaction) (Yuan et al. 2015; Shu et al. 2017).

During navigation in confined waters such as a narrow channel, ship handling is significantly affected by interaction and HI effects, which can strongly affect the manoeuvring characteristics of a vessel and results in changes in the speed, stropping distance, draft, trim and turning circle. Consequently, when a ship sails in narrow or limited seas, it could face a serious risk of contact grounding, or even collision as a result of the combined influence of many factors. Also, the relative safety distance is considerably shorter, as is the reaction time required to take evasive actions (Vantorre et al. 2017; Zhou et al. 2023).

Regarding S2S interaction, DeMarco Muscat-Fenech et al (2022) claim that the lateral distance between the vessels, position of the vessels with respect to each other along the direction of motion, hull dimensions, hull draft, speed and acceleration, water depth and secondary influences from the propellers and rudder are contributing parameters to the level of the HI during navigation in calm waters.

2.4 Ship Bridge Systems

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. Some of the most commonly used instruments on a ship bridge are:

- Electronic Chart And Display Information System (ECDIS)
- Automatic Identification System (AIS)

- Global Positioning System (GPS)
- RADAR Systems
- Conning Display
- Dynamic Positioning System (DPS)
- Heading Management Systems
- Gyrocompasses
- Sonar Systems
- Data Systems on Environment, etc.

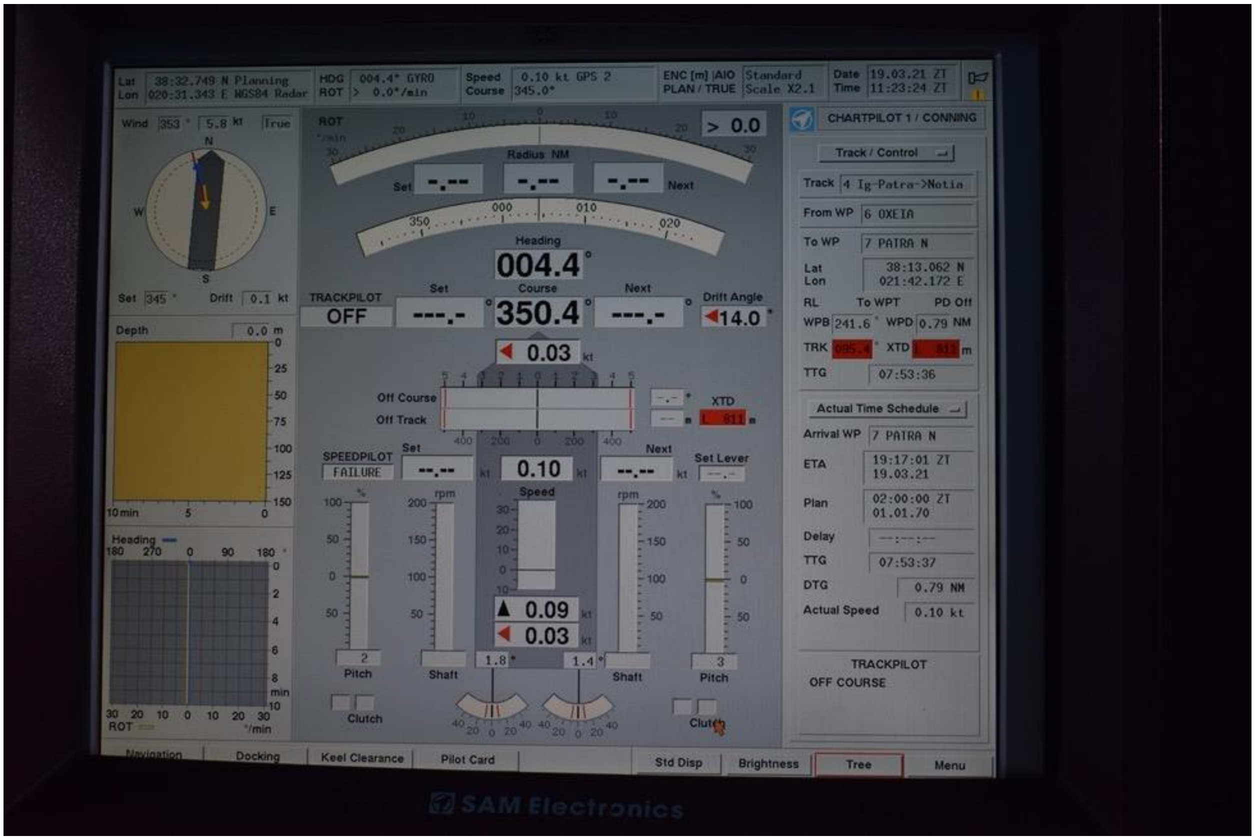
These systems coexist along with traditional tools like nautical charts, sextants, and magnetic compasses. They range from computer keyboards and touch screens to more traditional devices with a more direct physical relationship between the action (control) and the displayed result (displays) (Grech et al. 2019), such as moving a lever to control the propulsion system of a ship.

ECDIS serves as a digital navigation tool, displaying electronic charts and aiding route planning. AIS is used for vessel tracking and collision avoidance by broadcasting important information to other ships in the vicinity. GPS is crucial for accurate positioning and navigation, providing real-time information about a ship's location. RADAR systems are employed to detect nearby vessels and obstacles, particularly in adverse weather conditions or low visibility situations. A conning display may include orders, status information, route, and data, such as the Estimated Time of Arrival (ETA) and autopilot mode. Gyrocompasses ensure precise heading information, while sonar systems help with depth measurement and underwater obstacle detection. Figures 4 to 13 demonstrate these systems in action and examples of how these systems are positioned on a ship bridge.

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 (Figure 14). 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. 2020a; Rouse 2022).

Figure 4: An X-band RADAR system on a cargo vessel. Author's image.

Figure 5: An ECDIS display on a cargo vessel. Author's image.



Lat 38:32.749 N Planning
Lon 020:31.343 E WGS84 Radar
HDG 004.4° GYRO
ROT > 0.0°/min
Speed 0.10 kt GPS 2
Course 345.0°
ENC [m] |AIO Standard
PLAN / TRUE Scale X2.1
Date 19.03.21 ZT
Time 11:23:24 ZT
Wind 353 ° 5.8 kt True
Set 345 ° Drift 0.1 kt
Depth 0.0 m
ROT > 0.0
Heading 004.4°
TRACKPILOT OFF
Course 350.4°
Drift Angle 14.0°
XTD L 811 m
SPEEDPILOT FAILURE
Speed 0.10 kt
CHARTPILOT 1 / CONNING
Track 4 Ig-Patra->Notia
From WP 6 OXEIA
To WP 7 PATRA N
Lat 38:13.062 N
Lon 021:42.172 E
RL To WPT PD Off
WPB 241.6° WPD 0.79 NM
TRK 095.4° XTD L 811 m
TTG 07:53:36
Arrival WP 7 PATRA N
ETA 19:17:01 ZT 19.03.21
Plan 02:00:00 ZT 01.01.70
Delay --:--:--
TTG 07:53:37
DTG 0.79 NM
Actual Speed 0.10 kt
TRACKPILOT OFF COURSE

Figure 6: The conning display in a MFD of a Ro-Ro/Passenger Ship. Author's image.

Figure 7: The docking mode (left) and the conning mode (right) on an MFD system on a cargo vessel. Author's image.

Figure 8: A heading management system display (top) and a Global Maritime Distress and Safety System (GMDSS) panel (bottom) of a Ro-Ro/Passenger Ship. Author's image.

Figure 9: An echo sounder on a cargo ship. Author's image.

Figure 10: A DGPS display on board a cargo vessel. Author's image.

Figure 11: Various instruments on a ship bridge. Thruster indicators (top), camera view from starboard side (middle left), gyrocompass (middle bottom) and heading (middle top), wind direction and speed (middle right), vessel speed and microphone (bottom right).

Figure 12: (left) A magnetic compass on a cargo vessel. Author's image.

Figure 13: (right) A Pilot Plug device that allows pilots and other mariners to connect their own portable device to a vessel's Automatic Identification System (AIS). Author's image.

Schiff

Name: KATELINA

IMO-Nummer: 9485368

MMSI-Nummer: 236652000

Größe

Länge: 118,0 m

Breite: 18,0 m

Tiefgang: 6,20 m

Durchfahrtshöhe: 0,00 m

Conning-Position

X: 0,0 m Von: Zentrum

Y: 0,0 m Vom: Zentrum

Z: 0,0 m

☐ Benutze Conning x-Wert aus Sensor-Position

Sensoren

CENKIN

Navtronic Pilot Plug

Marcs Pilot Plug

GPS Intern

TRENZ AIS

GPS Maus

Figure 14: A Portable Pilot Unit in operation on board a cargo vessel. Author's image.

2.5 Decision Making and Expertise

It is an established fact that risk within the maritime industry is an inherent factor that can be reduced or acknowledged, but it cannot be totally removed (Berg 2013). Mariners encounter risks as a routine facet of their daily operations, and these risks can be effectively managed when operators possess a certain level of experience, training, and qualifications to facilitate informed decision-making. Consequently, decision-making assumes a pivotal role in the core operational activities of critical industries, manifesting itself through a dynamic work environment that aims to achieve operational objectives and employs knowledgeable, well-trained operators.

Expert knowledge can be developed by the accumulation of knowledge or skills that are gained over time. In this regard, the operator's work-related experience has been identified as fundamental to every working environment in facing with critical operational situations. Experience enables a person to interpret a situation in the context of viable objectives, pertinent cues, anticipated outcomes, and common responses. Experienced decision makers usually try to identify an acceptable course of action, which is often first one they consider and not the best one, and rarely have to pursuit another course of action (Klein et al. 1993). Empirical evidence has confirmed that a highly experienced operator exhibits the capacity to choose the most appropriate course of action even when confronted with high stress or time constraints (Yule and Paterson-Brown 2012).

The Recognition-Primed Decision (RPD) model of rapid decision-making, proposed by Gary Klein in 1993 (Klein 1993, p138), is a cognitive model that seeks to explain how individuals, particularly experts, make quick and effective decisions in complex and dynamic situations. This model challenges the traditional rational decision-making models that assume individuals carefully evaluate all available options and systematically examine the advantages and disadvantages before making a choice. In contrast, the RPD model proposes that experts rely on pattern recognition and their accumulated experience to swiftly identify and evaluate potential courses of action. Subsequently, they mentally simulate the anticipated outcomes of a limited set of options, foregoing exhaustive analysis. This selective approach allows them to make an initial decision based on their intuition and then continuously monitor and adjust their actions in response to real-time feedback. Klein's RPD model underscores the significance of expertise and pattern recognition in facilitating effective decision-making under conditions of uncertainty and time constraints, offering valuable insights across various domains, from emergency response to military operations. Overall, the RPD model provides valuable insights into the decision-making processes of experts in real-world, dynamic environments, emphasizing the role of pattern recognition and experience in guiding effective decision-making.

The main components of the Recognition-Primed Decision model are depicted in Figure 15 include:

1. *Recognition*: Decision-makers draw upon their past experiences, expertise, and knowledge to recognize patterns and cues in the current situation. These patterns are often related to similar situations they have encountered before. Recognition is a critical aspect of this model because it allows decision-makers to quickly identify relevant information without exhaustive analysis.
2. *Mental Simulation of Action*: Once a decision-maker recognizes a familiar pattern or situation, they mentally simulate the likely outcomes of various courses of action. This mental simulation helps them assess the feasibility and potential effectiveness of different options without fully evaluating each one.
3. *Comparative Evaluation*: Rather than evaluating every possible alternative, decision-makers typically focus on a limited set of options that they believe are most likely to succeed based on their recognition and mental simulation. This comparative evaluation helps them make a preliminary choice.
4. *Action*: After selecting a course of action based on recognition and mental simulation, decision-makers act. They continuously monitor the situation and adjust their actions as needed, based on real-time feedback.
5. *Feedback Loop*: The RPD model includes a feedback loop that allows decision-makers to refine their decisions as new information becomes available. If their initial choice does not yield the expected results, they may modify their course of action based on the updated information.

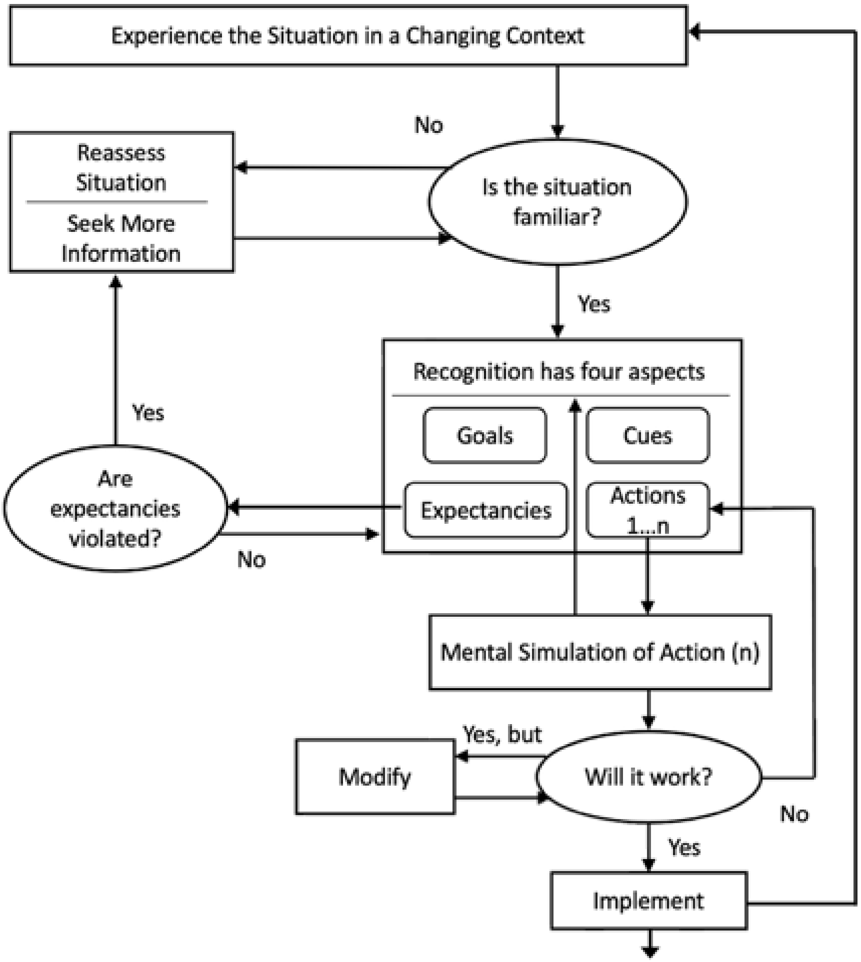


Figure 15 The Recognition-Primed Decision model (Klein 1993)

2.6 Human Error and Situation Awareness

The human element prevails as a major factor in 58-85% of maritime accidents worldwide (Grech et al. 2002; Lützhöft and Dekker 2002; Baker and McCafferty 2005). 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).

According to Perrow (2011), issues in coordination were among the major human factors aspects that led to maritime accidents were. Pourzanjani and Cheng (2001) observed that 46% of duty officers had not clearly indicated their intention to manoeuvre after analysing 59 accidents at sea, and the reason for this omission was further explored by Chauvin and Lardjane (2008), who pointed out that the existence of different systems could be the potential cause of this failure. Aside from the aforementioned human errors, existing research shows that many other significant elements, such as insufficient manning, lack of expertise, inter-ship communications, and so on, have led to maritime accidents (Qiao et al. 2020).

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 Situation Awareness (Porathe 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 recognise 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 (Lützhöft and Dekker 2002; Leveson 2011; Grech and Lemon 2015).

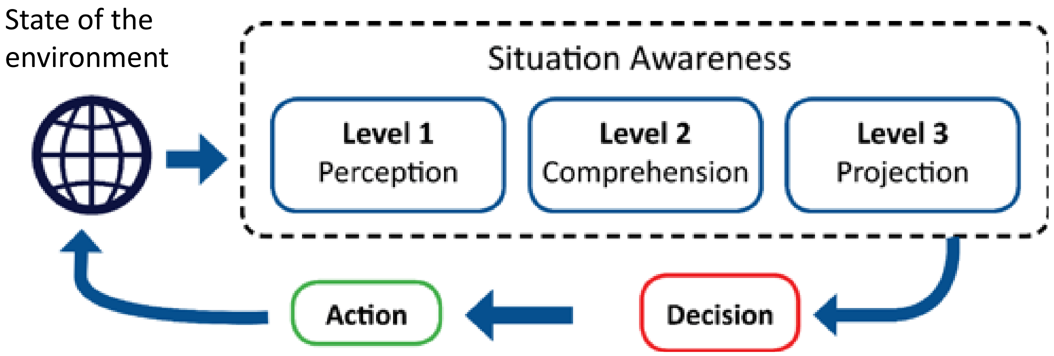


Figure 16 The Three Level Model of Situation Awareness and feedback loop (based on Endsley 1995)

SA in the maritime domain can be described using the example of the activities on board a ship for collision avoidance (Grech et al. 2019):

1. The presence of another vessel must be *recognised* visually or by using artifacts such as the RADAR or an AIS monitor.
2. It must be *evaluated* if the two ships are on a crossing path; if not, no threat of collision exists.
3. If there is a threat of collision, it must be *assessed* if the two ships *will be* at (nearly) the same place at (almost) the same time.
4. It must be *decided* which ship is going to give way (according to the Collision Regulations, or COLREGs).
5. *Action* must be taken to avoid collision.
6. Finally, action must be taken to ensure that the manoeuvre produces the *intended effect*.

Based on the Three Level SA model by Endsley (Fig 16), we can describe this example in three phases:

1. Perception (Level 1)— The presence of another vessel must be identified.
2. Comprehension and Projection (Levels 2 and 3)—Will courses intersect? Is there a collision risk? Which ship is going to give way?
3. Execution (Decision and Action)—Actions to prevent collision.
4. Feedback loop (Updated state of the environment)—Ensure that the anticipated impact is achieved.

Similar to the description of the collision avoidance by Grech et al. (2019) Sharma et al. (2019) have described how a navigator of a vessel can build SA while interacting with a dynamic system.

1. Level 1 SA: GPS position, speed, course, heading, targets, and other parameters need to be initially *perceived* by the operators so that they can be aware of the external state of environment.
2. Level 2 SA: parameters such as "Closest point of approach (CPA)" to target or "Time to closest point of approach (TCPA)" may give a deeper significance in terms of the existing targets. This level of SA provides a *meaning of the existing state* and assists the navigator to determine the most suitable course of action (if any).

3. Level 3 SA: vector extension of targets and radar simulation offer a *projected perspective* on the basis on which a future outcome of the system state may be predicted.

In case the perception or the comprehension of the situation is unsuccessful, the safety of the vessel and the activity are compromised. The perception of the situation is the first phase in the SA model, which could be "the presence of other vessel" or "direction towards shallow water." However, in more general terms, it can be described as "what is the maritime situation, and what do we need to do to describe the total situation of the ship?" (Grech et al. 2019).

Chapter 3 Elicitation and representation of expert knowledge

Knowledge elicitation has historically been linked to the systematic study of proficient domain practitioners with an overall goal of understanding the interaction of cognition, collaboration, and complex artefacts. The field setting is the reference point in these research endeavours, where teams of domain experts deal with significant challenges with the help of technical and other kinds of artefacts (Hoffman and Lintern 2006).

This chapter reviews and argues on the methods that have been used in the two studies of the thesis. First, the Applied Cognitive Task analysis is presented, along with a review of Cognitive Task Analysis methods. The second part is a review of Fuzzy Cognitive Maps, a participatory mapping approach. The chapter contains the detailed presentation of each method, their comparison to other popular methodologies and argumentation in favour of choosing ACTA and FCM, notable applications, and details on their techniques.

3.1 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 (Militello and Hutton 1998; Drury and Darling 2007; Stanton et al. 2013). CTA methods can support the interviewed SMEs into articulating their domain knowledge and the researchers/interviewers 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 (Klein et al. 1989)and the Applied Cognitive Task Analysis (ACTA) by Militello and Hutton (1998). While the GDTA is a powerful methodology that can offer enriched and in-depth data for a critical navigational goal, it would require much more contact with SMEs, many rounds of interviews and more resources than those available. The CDM is a retrospective interview approach that employs a collection of cognitive probes to actual, non-routine events that involve expert decision-making. After selecting an incident, the interviewer uses a semi-structured interview format to investigate several facets of the decision-making process. The CDM was also eliminated because its focus is mainly on non-routine and unusual events, for which domain experts are called to access their memories. It should be noted that serious incidents and accidents in maritime pilotage are quite infrequent, high consequence events with various sensitive legal and financial issues; therefore, it would be unlikely to find and recruit pilots with relevant experiences willing and permitted by non-disclosure agreements to account on such events.

ACTA 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.

3.1.1 Applications of ACTA

ACTA has been successfully used to understand expertise in a wide range of areas including: business aviation piloting (Latorella et al. 2001), helicopter pilots (Minotra and Feigh 2017; Tušl et al. 2020), unmanned aircraft system pilots (Lercel and Andrews 2021), unmanned vehicles (Drury and Darling 2008), medical contexts (Militello and Hutton 1998; Craig et al. 2012; Morozova et al. 2017; Pickup et al. 2019), crime scene examiners (Martindale et al. 2017), financial decision-making (McAndrew and Gore 2013), weather forecasting (Hoffman et al. 2001) and high-level coaches within strength and conditioning (Downes and Collins 2021). Thereby, it can be considered as fitting to help in understand better marine pilot performance in critical manoeuvres.

The first implementation of ACTA analysis was performed on the safety-critical task of fire rescue (Militello and Hutton 1998). Drury and Darling (2007) adapted ACTA to study the personnel of an operations centre for Predator Unmanned Aircraft Systems within a three-day period and argue that ACTA can be applied to quickly understand the major cognitive challenges for other time-critical and safety-critical tasks. However, prior to adapting ACTA, the authors performed observations and augmented the methodology with questions about coordination procedures to obtain more contextual data. In a notable study of the maritime domain, Brödje et al. (2011) adapted ACTA in a case study with Vessel Traffic Service (VTS) operators (VTSOs). The researchers developed a mid-fidelity interactive simulation for the part of the SI by using a projection to display static geographic information on a whiteboard, that are similar to those in system displays that VTSOs use, and cardboard vessels to act as targets in a way that they represent a normal traffic scenario. They assessed the adapted SI using the Hoffman method evaluation criteria (Hoffman 1987) and argued that this adaptation allowed for studies with the VTSOs in a more familiar context compared to the event-based low fidelity simulation and enriched the data collection.

3.2 Fuzzy Cognitive Maps

3.2.1 Cognitive Maps

A cognitive map (CM) is a graphical representation of the content and structure of an individual's belief system (Eden 1992). The fundamental principles and outlines of the CM technique were first introduced by Tolman (1948). Later, Axelrod (1976) introduced cognitive maps for representing social scientific knowledge as a casual-based mapping technique where concepts representing elements of a complex problem are organized and structured using arrow diagrams. A CM can describe how individuals perceive a specific situation or problem and provides the decision makers with a simplified portrayal of the external reality (Bertolini and Bevilacqua 2010).

The visual representation of a CM takes the form of a directed graph with signed connections that include feedback (Figure 17). This graph consists of nodes and interconnected links. Each concept or factor is represented as a node, and the links between them are represented as arrows (Mendoza and Prabhu 2009). These links indicate how the concepts influence each other and how changes in one concept might affect other concept(s). Each arrow indicates an influence which can be positive or negative. A positive link from node A to node B means that A causally increases B. Respectively, a negative link from node A to node C shows that A causally decreases C.

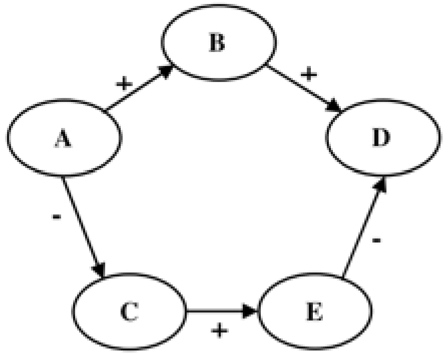


Figure 17 An example of a Cognitive Map

CMs have been used to address complex problems, formulate strategies, facilitate decision-making and negotiation. They have also been used to translate tacit knowledge (information, skills, attitudes, experiences, and judgments) into practice to capture individual and organizational cognition as well as to establish common mental models. A CM can describe how people perceive a particular situation or problem and provides the decision makers with a streamlined representation of the outside world (Gray et al. 2015).

3.2.2 Fuzzy Cognitive Maps

Fuzzy Cognitive Mapping is a semiquantitative and dynamic system modelling technique that was developed by Kosko (1986) to extend Axelrod's (1976) cognitive maps. Kosko defined a Fuzzy Cognitive Map (FCM) as "*a relation model map to express knowledge as a signed digraph and infer the cause-effect relationship between the concepts*". FCMs introduced fuzziness to Cognitive Maps, by using numeric descriptions (fuzzy binaries) of causal influences, instead of positive or negative symbols (Papageorgiou et al. 2018). FCM applies fuzzy logic to CMs, making it possible to predict changes in the concepts represented in cognitive maps.

Basic concepts of Fuzzy Cognitive Maps

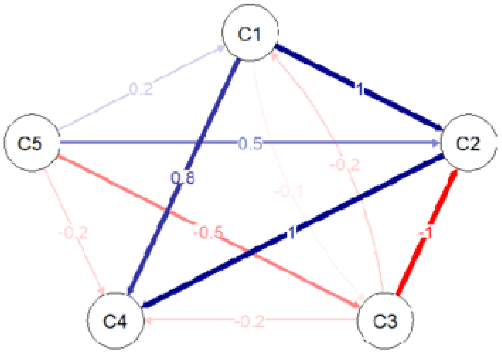
In FCMs, each concept is modeled as a variable C_i, i=1,2,…N that can take fuzzy or discrete values according to the problem data (Figure 18). The concepts can be continuous variables, e.g. the amount of something; ordinal variables, e.g. more or less of something; dichotomous variables, indicating the presence or absence of something (Bertolini and Bevilacqua 2010).

When it comes to the process of knowledge building, the interaction between two concepts exhibits a certain level of ambiguity. A weight W_{ij} can be used to express the degree of influence. Weights take values in the interval [-1,1]. The closer the weight is to -1 or 1, the stronger the influence.

There are three distinct types of cognitive relationships between nodes, expressing the manner in which one node influences other (Dikopoulou et al. 2018):

- $w_{ij} = 0$ indicates no causality between concepts;
- $w_{ij} > 0$ indicates a causal increase (i.e., C_j increases as C_i increases, and C_j decreases as C_i decreases);
- $w_{ij} < 0$ indicates a causal decrease (i.e., C_j decreases as C_i increases, and C_j increases as C_i decreases).

A FCM of n concepts could be represented mathematically by a $n \times n$ weight matrix (W). Figure 18 shows an example of a FCM with its corresponding adjacency weight matrix.



$$\Rightarrow \quad W = \begin{array}{c|ccccc} & C_1 & C_2 & C_3 & C_4 & C_5 \\ \hline C_1 & 0 & 1 & -0.1 & 0.8 & 0 \\ C_2 & 0 & 0 & 0 & 1 & 0 \\ C_3 & -0.2 & -1 & 0 & -0.2 & 0 \\ C_4 & 0 & 0 & 0 & 0 & 0 \\ C_5 & 0.2 & 0.5 & 0.5 & -0.2 & 0 \\ \hline \end{array}$$

Figure 18 Fuzzy cognitive map (left) and the correspondent weight adjacency matrix (right), showing the positive and negative causal influences (adapted from Dikopoulou et al. 2018).

FCM Inference and Simulation

Taking into consideration the interrelations between the concepts of a FCM, the corresponding adjacency matrix can easily be formed. Every concept C_i in the graph has a value V_i that expresses the quantity of its corresponding physical value derived after the defuzzification described above (Kokkinos et al. 2018). The value V_i of C_i is computed in each simulation step and it basically indicates the influence of all other concepts C_j to C_i (inference). The most popular inference rules are: (a) Kosko's inference, (b) Modified Kosko's inference, and (c) Rescale inference, as shown in the following three activation functions, respectively (Dikopoulou 2021):

Kosko:

$$V_i^{(\kappa+1)} = f\left(\sum_{j=1, j\neq i}^{n} w_{ji} * V_j^{(\kappa)}\right) \qquad \text{(a)}$$

Modified-Kosko:

$$V_i^{(\kappa+1)} = f\left(V_i^{(\kappa)} + \sum_{j=1, j\neq i}^{n} w_{ji} * V_j^{(\kappa)}\right) \qquad \text{(b)}$$

Rescale: $$V_i^{(\kappa+1)} = f\left((2 * V_i^{(\kappa)} - 1) + \sum_{j=1, j\neq i}^{n} w_{ji} * (2 * V_j^{(\kappa)} - 1)\right) \quad \text{(c)}$$

$V_i^{(\kappa+1)}$ is the value of a concept C_i at simulation step $\kappa + 1$, $V_j^{(\kappa)}$ is the value of a concept C_j at the simulation step κ, w_{ij} is the weight of the interconnection between concept C_i and concept C_j, κ (Greek letter Kappa) is the interaction index at every simulation step. Also, *f*(.) is the threshold (transformation) function that can be: (d) bivalent, (e) trivalent, (f) sigmoid or (g) hyperbolic, as shown in the following four equations, respectively (Dikopoulou 2021).

Bivalent: $$f(x) = \begin{cases} 1, & x > 0 \\ 0, & x \leq 0 \end{cases} \quad \text{(d)}$$

Trivalent: $$f(x) = \begin{cases} 1, & x > 0 \\ 0, & x = 0 \\ -1 & x < 0 \end{cases} \quad \text{(e)}$$

Sigmoid: $$f(x) = \frac{1}{1 + e^{-\lambda x}} \quad \text{(f)}$$

Hyperbolic tangent: $$f(x) = tanh(\lambda * x) = \frac{e^{\lambda x} - e^{-\lambda x}}{e^{\lambda x} + e^{-\lambda x}} \quad \text{(g)}$$

where λ is a real positive number ($\lambda \geq 0$), that determines the steepness of the continuous function f and *x* is the value $V_i^{(\kappa)}$ on the equilibrium point. The system's FCM model takes the starting values of concepts and weights based on experts' knowledge and expertise for the real system and then permits it to interact. The value V_i of a concept is influenced by the values of concepts associated to it at each step, and it is updated in accordance with the inference rule. This process is repeated until i) the system converges in a fixed equilibrium point where the difference between two subsequent values of the outputs must be equal, $V_i^{\kappa} = V_i^{(\kappa+1)}$, or lower to the residual ε (epsilon), ii) a limited cycle is attained or iii) a chaotic behavior emerges (Dikopoulou 2021).

It should be noted that the sigmoid threshold function ensures that the calculated value of each concept will belong to the interval [0, 1]. When the values of concepts can be negative and their values belong to the interval [−1, 1], the hyperbolic tangent function can be used instead.

The sigmoid function is commonly used in most studies to generate system inference (Papageorgiou and Salmeron 2013; Papageorgiou 2014). Furthermore, depending on the problem, scenario analysis can be performed with either all or a subset of concepts activated, depending on the aim of the study. As a result, alternative scenarios are developed to estimate the system's inference (Kosko 1986), answering the "what - if" conditions.

Fuzzy set Theory

Fuzzy set theory is characterized by grades of membership of the interval -1 to 1, $\mu: U \rightarrow [-1, 1]$. A fuzzy set $\tilde{A}$ is defined by a membership function within a specified range. If $\mu_{\tilde{A}}(x)$ equals with zero, the element x does not belong to the fuzzy set $\tilde{A}$. If $\mu_{\tilde{A}}(x)$ equals with one, the element x is a member to the fuzzy set $\tilde{A}$. If $\mu_{\tilde{A}}(x)$ has a value in the interval $[0, 1]$, the element x belongs in part to the fuzzy set $\tilde{A}$ (Zadeh 1965; Dikopoulou et al. 2017).

Linguistic terms like “little”, “somewhat”, “strongly”, and more, can be used instead of numeric values to describe the cause-effect relationships (Papageorgiou et al. 2019). For example, the eleven linguistic variables could be determined as: *T(influence} = {negatively very strong, negatively strong, negatively medium, negatively weak, negatively very weak, zero, positively very weak, positively weak, positively medium, positively strong, positively very strong}*. Every linguistic variable is linked to a membership function in the range [-1, 1], $\mu = \{\mu_{nvs}, \mu_{ns}, \mu_{nm}, \mu_{nw}, \mu_{nvw}, \mu_{z}, \mu_{pvw}, \mu_{pw}, \mu_{pm}, \mu_{ps}, \ \mu_{pvs}\}$. To convert the linguistic variable into precise numerical values, the Centre of Gravity (CoG) defuzzification method can be used (Zadeh 1986).

Properties of FCM

The core purpose of an FCM lies in investigating how these causal influences spread throughout a system during modifications or interventions. Understanding the dynamics of the system stems from the interaction of concepts, driven by the cognitive strength of their relationships (Douali 2015). FCM analysis examines how modifications to a small number of factors propagate through the system, rather than how the actual values of factors or ideas change[i]. The FCM developed by Kosko (1994) is an indicative example of the dynamic nature and the feedback process of a cognitive map that illustrates how bad weather influences daily driving speeds on a Californian highway (Figure 19).

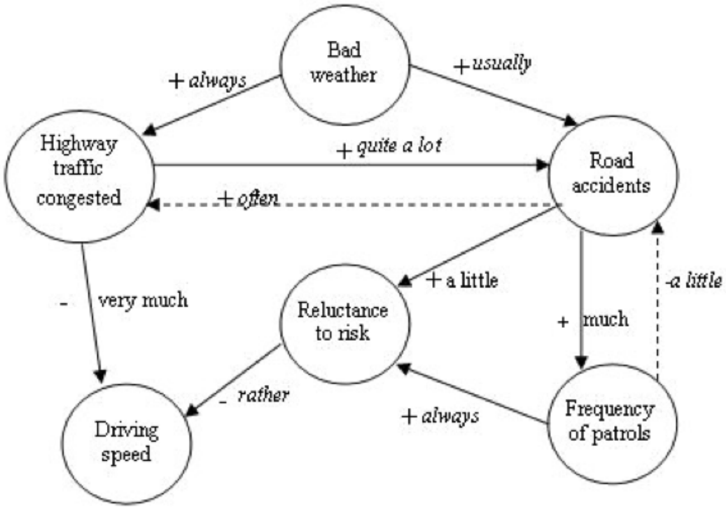


Figure 19 Example of a fuzzy cognitive map developed to analyze driving risks (Adapted by Kosko 1994)

In this example, the arrows, or fuzzy rules, are assigned non-quantitative weights like "usually" and "a little." The FCM exhibits two compact feedback loops or cycles that demonstrate the continuous flow of information, influences and causalities, propagating in two directions as follows:

- In the first feedback loop, traffic congestion on the highway significantly increases the road accidents (“quite a lot”), and the road accidents frequently contribute to further traffic congestion on the highway (“often”).
- In the second loop, road accidents increase the frequency of police patrols on the road (“much“), but a greater frequency of the police patrols aids in reducing the road incidents (“a little”).

Fuzzy Cognitive Mapping can be easily implementable, especially valuable within intricate, data-limited contexts. FCMs can be used in a participatory approach to aggregate accumulated experience, insights, or viewpoints of specialists. Even in situations where concepts and data classifications are vaguely defined, FCM can be used to derive valuable insights. Maps produced by individuals can also be aggregated to produce a combined FCM, enriched with knowledge from all experts and stakeholders (Olazabal et al. 2018).

3.2.3 FCM Structural Analysis

FCM structural analysis uses graph theory indices and focuses on map topology analysis. Its goal is to characterise the overall network architecture and identify concepts of particular interest (Yoon and Jetter 2016). The measurements range from those that involve counting the variables (N) and connections (C) of the map or categorization to those that are more complicated and subtle (Obiedat 1994; Gray et al. 2014; Yoon and Jetter 2016; Engome Tchupo and Macht 2022).

Density

Density (D) is the number of connections in the map divided by the maximum number of connections possible for all *N* variables. A large number of causal relationships among the variables will result in high density and is measured by the following equation (Özesmi and Özesmi 2004; Gray et al. 2014):

$$\mathrm{D}= \frac{C}{N(N-1)} \qquad \text{(h)}$$

Alternatively, if the map allows for self-loops, the maximum number of connections possible is N^2 (Özesmi and Özesmi 2004) and density is calculated as follows:

$$\mathrm{D}= \frac{C}{N^2} \qquad \text{(i)}$$

Types of variables

The type of variable indicates how a variable interacts with other variables in a map. Different types of variables can help in analysing the structure of a CM. There are three types of variables and they are defined by their outdegree [$od(v_i)$] and indegree [$id(v_i)$] (Eden 1992; Özesmi and Özesmi 2004):

- transmitter variables (forcing functions, givens, tails)
- receiver variables (utility variables, ends, heads), and
- ordinary variables (means)

Transmitter variables can be perceived only as a cause to other elements within the CM. Receiver variables can be perceived only as an effect of other elements. Ordinary variables are those elements that have both at least one cause and at least one effect relationship (Nikas and Doukas 2016).

Outdegree is the row sum of an adjacency matrix variable's absolute values. It represents the total number of connections (a_{ij}) that exit the variable, where N is the total number of variables.

$$od(v_{\mathrm{i}}) = \sum k = 1N\bar{\mathrm{a}}_{\mathrm{ik}} \qquad \text{(j)}$$

Indegree is the column sum of a variable's absolute values. It indicates the total strength of the variables that enter the variable.

$$id(v_{\mathrm{i}}) = \sum k = 1N\bar{\mathrm{a}}_{\mathrm{ki}} \qquad \text{(k)}$$

The outdegree of transmitter variables is positive, $\mathrm{od}(v_{\mathrm{i}})$, while the indegree is zero, $\mathrm{id}(v_{\mathrm{i}})$. The indegree of receiver variables is positive, $\mathrm{id}(v_{\mathrm{i}})$, while the outdegree is zero, $\mathrm{od}(v_{\mathrm{i}})$. Ordinary variables have a non-zero indegree and outdegree. Ordinary variables, depending on the ratio of their indegrees and outdegrees, might be more or less receiver or transmitter variables (Özesmi and Özesmi, 2004).

Centrality

The centrality (immediate domain, total degree [td(v_i)]) of a variable is the summation of its indegree (in-arrows) and outdegree (out-arrows) (Bougon et al. 1977; Eden 1992; Harary et al. 1965):

$$c_{\mathrm{i}} = td(v_{\mathrm{i}}) = od(v_{\mathrm{i}}) + id(v_{\mathrm{i}}) \qquad \text{(l)}$$

Calculating the centrality can assist in evaluating the impact of a variable in a CM. Centrality reveals the degree to which the variable interacts with other variables and the cumulative strength of these connections. An FCM variable might be more significant while having fewer connections if the weights of the connections are greater.

Complexity

The ratio of number of receivers (R) to transmitter (T) variables (R/T) can indicate the complexity of a CM. Complex maps will have larger ratios, because they define more utility outcomes and less controlling forcing functions (Özesmi and Özesmi, 2004).

3.2.4 Application of Fuzzy cognitive maps (FCM) in human factors – ergonomics research

Jones et al. (2011) used FCMs to develop SA-FCM for improving the representation of situation awareness for military operations. They claim that the model can simulate how Infantry Platoon Leaders make decisions during field missions and mimic human cognition as it relates to SA. They used the Goal Directed Task Analysis by Endsley et al. (2003) to depict the relationship between goals, decisions, and SA requirements and the interrelationships of SA Requirements as they relate to each goal. The SA requirements include the features of the environment where a military operation takes place known as Mission, Environment, Terrain and Weather, Troops, Time Available and Civil Considerations (METT-TC factors). The FCM assisted in the depiction of relationships between relevant pieces of information that are in higher cognitive levels, which are prerequisites for effective decision-making. According to the authors, the SA-FCM can represent and help the human decision-maker understand the comprehension (Level 2 SA) and projection (Level 3 SA) of how the data impacts current and future situations. Özesmi and Özesmi (2014) noted that the SA-FCM model preserves the hierarchical structure of each SA requirement identified within the GDTA hierarchy and provides an SA rating at each level.

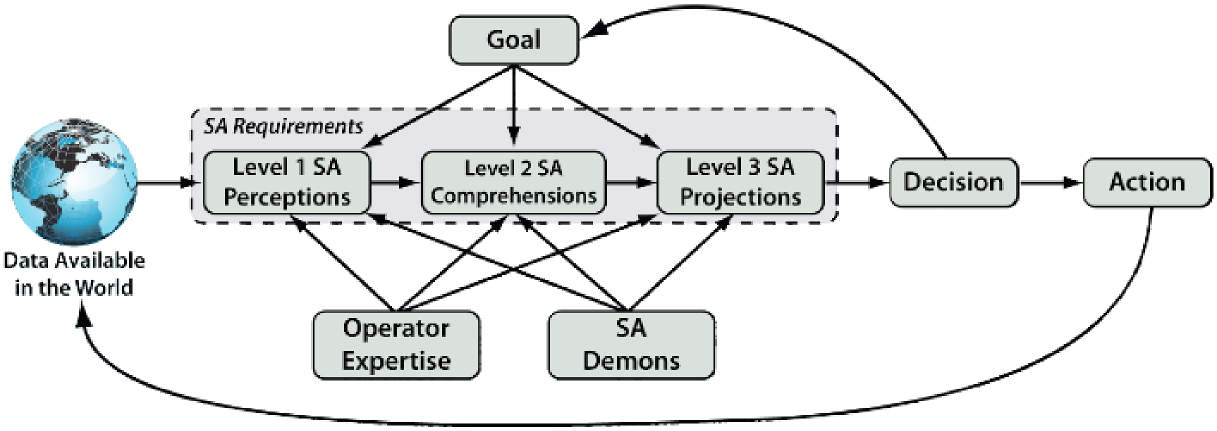


Figure 20 The SA FCM model from Jones et al (2011) for brigade officers

Their approach was to (1) Translate GDTA into FCM nodes, (2) Define the relationships between nodes (3) Assess the weights that express the strength of relationships (4) Evaluate the FCM. Subject matter experts were involved in all steps. The model validation process was based on a Turing test where 2 SMEs were asked to assess the model's performance for one subgoal from the GDTA in developing a mission plan for six scenarios. The preliminary validation results indicated that the SA-

FCM model can support decision-making in real-time by effectively comprehending and projecting a scenario based upon the METT-TC factors that are used by a human decision maker. In this way, the SA-FCM can help platoon leaders with the higher-level portions of the decision task that many soldiers may have trouble with, particularly those who are less experienced.

Irani et al. (2015)used FCMs to investigate the dynamics of decision-making concerning investments in information technology and information systems. The authors examined the characteristics of these investments from the perspective of behavioural economics, causality, input-output (IO) equilibrium, and the broader concept of the depletion of executive energy function. Their model included human factors, such as views and needs of the relevant stakeholders and decision makers, as well as human resources, including management and staff time and training. Additionally, organizational factors such as structure, leadership, business processes, organizational and managerial aspects, and organizational culture were integrated into the model.

Their research approach was based on an exploratory case study research strategy for a manufacturing company. The data collection phase included interview, observations, and review of company documentation. The data coding process used Qualitative Content Analysis (QCA). The researchers observed the frequency with which interviewees referred to individual factors and observed their responses when the latter were prompted explain forecasting factors related to their expertise or area of responsibility. Each factor's significance was graded as "High," "Medium," "Low," or "Do Not Know." Principles from behavioural economics were used to gain deeper insight in the QCA concepts. Finally, the data analysis phase used the FCM, input-output modelling, and the decision fatigue framework. Within their FCM, the authors incorporated concepts like the anchoring effect, agency friction, confirmation bias, environment effect, feedback loops, loss aversion, reference dependence, and status quo bias to facilitate their analysis.

Similarly, Jiang et al. (2014) proposed an FCM-SA model tailored for dynamic decision-making scenarios, where they presented how SA can be modelled using FCM approach to understand the inner dynamics of information processing of SA system. Firstly, the identification of each concept was initially done within the three layers of an SA decision-making model defined by authors that comprised of three layers, namely system-interface layer, SA-Judgement layer, and operator cognition layer. Second, the construction of causal relationships among these elements, specifying the strength of these relationships on a five-tier scale, ranging from highly positive influence to highly negative influence. Third, they conducted interviews with ten participants that were experts and researchers from the domains of Human Computer Interaction, Human Factors, Cognitive Science and Teleoperation Control Systems. These interviews were done either individually or in groups of 3 or 4 people, where participants were asked to draw concepts, they deemed significant and believed should be included in the model. Examples from other areas were also used to guide the participants in the mapping process. Fourth, all the concepts were then recorded and presented to the interviewees who discussed the connections and came up with the direction of causality and its strength for their FCMs. Final weights of the connections between concepts were calculated using a score function (weighted sum).

A hybrid method was proposed by Ma et al. (2022) that integrated the Human Factors Analysis and Classification System (HFACS), Decision Making Trial and Evaluation Laboratory (DEMATEL), and FCM to define and analyse the static and dynamic interrelations of human factors contributing to maritime accidents. The authors used information from 240 ship collision investigation reports to define a maritime accident scenario instead of capturing knowledge from experts and stakeholders. Grounded theory was employed to identify and structure 49 human factors at different levels within the HFACS model. Subsequently, they used the DEMATEL method to determine the influencing degree, influenced degree, centrality, and causality of each factor based on a quantitative comparison between each pair of human factors. The FCM model was then developed to realize dynamic prediction and diagnostic inference of these factors. The authors claim that their results on human factors analysis are more more objective and comprehensive, and consistent with the results of similar studies. Further, they argue that such results could not be obtained using traditional risk analysis approaches, such as the Swiss Cheese model, Accimap, STAMP, and more. Even though their approach is novel and utilizes the advantages of HFACS, DEMATEL and FCMs, the complexity and uncertainty of human factors, may results in lack or omission of information, which highlights the need for expert judgement in various stages of such studies. Also, the paper does not provide any information on validation of results. Some researchers (Bowles and Pelàez 1995a, 1995b, 1996, Kosko 1985, Warren 1995 as cited in Bertolini and Bevilacqua 2010) have suggested that the experts' opinion is essential for determining the variables needed to describe the system being studied, the existence of causal relationships and their direction, and the polarity and power of the causal links.

The FCM approach has also been used in studies for health and safety, human reliability, and human behavior. Asadzadeh (2013) conducted an analysis and evaluation of the combined Health, Safety, Environment and Ergonomics (HSEE) factors using an FCM approach and identified the factors that significantly impact the system performance. Mei et al. (2014) used FCM in a study on the transmission of infectious diseases to conceptualize and examine the relationships between emotions and cognition for adaptively guiding behaviour based on individual decision rules. Bertolini (2007) applied FCM in human factors to assess and analyse human reliability in manufacturing. Aju kumar et al. (2015) proposed an FCM model to understand how human factors and their interactions influence human reliability in maintenance. Bevilacqua et al. (2012) applied an FCM approach to investigate the significance of various factors, including the behavioural aspects of workers, within an industrial setting. Using the FCM model, they calculated the maximum cumulative impact for each type of injury. Based on their results, they suggested suitable measures to be implemented in the workplace regarding policy, procedure, and training. Buche et al. (2010) suggested employing FCMs to explicitly depict internal emotional states in autonomous entities' responses to external stimuli in virtual environments, offering a tool for behaviour specification, control, and adaptation through observation.

Chapter 4 Identifying cognitive challenges for safe ship overtaking in restricted waterways

This chapter presents the approach, procedure, and results of the domain familiarisation study (first) and the ACTA study (second). The focus of the first study was to obtain familiarization with various types of ship bridge environments, manoeuvring and pilotage, and to develop ethnographic interpretations of experience and work. The aim was to comprehensively investigate maritime pilots' work activities through a series of training sessions, open structured interviews with expert mariners, review of accidents and field observations. The results from the first study were used to create a case study in the Bremerhaven region that facilitated the second study.

The aim of the second study was to obtain a detailed description of the overtaking manoeuvre and to understand the cognitive processes of mariners when they perform this task in the fairway the Bremerhaven region. To achieve this, a qualitative study was performed using an adaptation of Applied Cognitive Task Analysis (ACTA) with five highly experienced sea pilots in northern Germany. Based on the content analysis of the interviews and the other data collection activities, six phases of the overtaking task and twelve high level cognitive challenges were identified that significantly affect pilots' decision making and situation awareness during overtaking.

The results from this chapter contribute to the following research questions:

1. RQ1: While navigating in confined waters, how do maritime pilots decide to perform an overtaking manoeuvre?
7. RQ2: What are the cognitive processes of maritime pilots during an overtaking manoeuvre?
8. RQ3: What are the cognitive challenges that maritime pilots face when they decide to perform overtaking with safety?

4.1 Methodological approach

The first step in the research activities was to contact several sea pilot associations from 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 at the time of the study. 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.

4.2 Study 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 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, an exploratory review was conducted on ship bridge equipment interfaces, IMO regulations, procedural manuals, and roles and responsibilities of pilots and the ship bridge crew. Another step was to study 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).

4.2.1 Explorative Interviews

Two highly experienced sea pilots were invited in to participate in open structured interviews from one district in Bremerhaven. The goal was to obtain an overview of critical manoeuvres and additional background information using an abstracted scenario where two vessels meet in a narrow channel (Figure 21). Each interview lasted about 1,5 h. Both pilots described the scenario as general but appropriate to obtain some broad knowledge on the activity of pilotage in confined waters. They emphasized that some constraints that need to apply, such as the type of ships used in the scenario, the location, traffic, weather conditions and the cargo. Without these constraints they could not offer answers, as this knowledge guides their strategical and tactical thinking in such scenarios. Their feedback was valuable in shaping the next steps by creating a case study and a scenario that can elicit knowledge effectively for a more critical scenario.

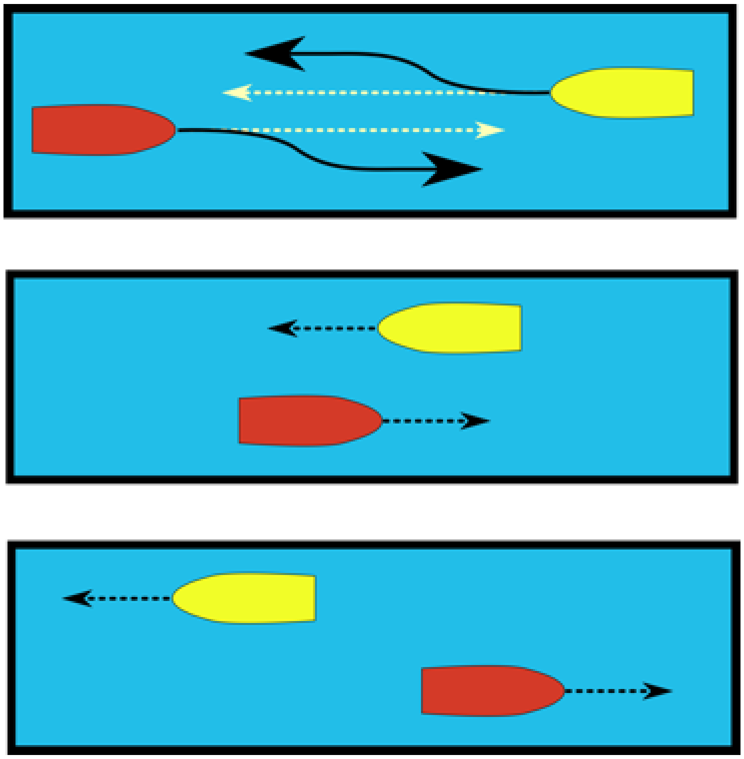


Figure 21 The scenario used in the explorative interviews. Vessel A (red) and Vessel B (yellow) interact in a narrow channel.

4.2.2 Field trip

Following the interviews, 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 Figure 22. The 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. 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.

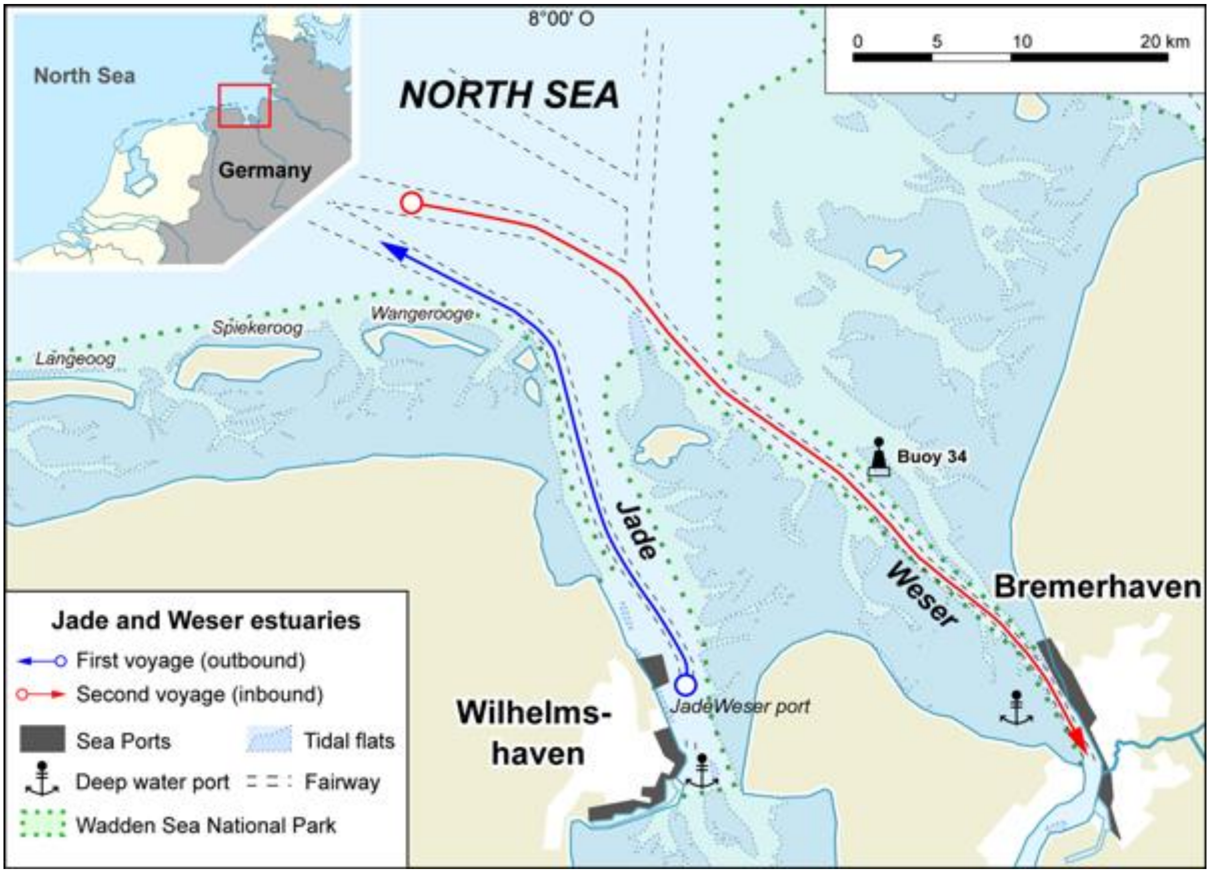


Figure 22 The area of the outbound first voyage (blue line) and the inbound second voyage (red line) in the Jade–Weser estuary. Adapted from "Übersichtskarte Jade- und Wesermündung" by Alexrk, used under CC BY-SA 3.0.

4.3 Study 2: Applied Cognitive Task Analysis

There are over 100 CTA related techniques related to assessing the cognitive aspects of a task and they are popular in studying complex man – machine systems. The main disadvantage of CTA is the considerable amount of time and resources needed for both investigators and experts that participate. There is also lack of consensus about which approach should be followed in which situation (Stanton et al. 2013). To choose the most appropriate approach, first a literature review was conducted to identify existing methods for eliciting expert knowledge in the maritime domain and in complex dynamic sociotechnical environments that share similar characteristics, such as multiple and partly conflicting goals, negotiation, human technology cooperation, environmental complexity, and time-critical operations. The criteria for choosing a methodology were to gather the data in a non-disruptive manner for the participants, who would be experienced mariners on active duty, and to collect as much data as possible within a reasonably timed interview session with one SME at a time.

For this study, the ACTA technique was chosen, 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). It 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.

The approach for implementing ACTA was 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). The author 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 was 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 the technique used by Brödje et al. (2010) was adapted and built a half interactive low fidelity simulation to serve the purposes of our research. Finally, all the gathered data were reviewed, and a highly structured content analysis was conducted to develop knowledge representations. The Overview Task Diagram and the Cognitive Demands Table representation frameworks were used, as defined by the ACTA toolkit.

4.3.1 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 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 years) on the date of the interviews.

4.3.2 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. Appendix B includes the detailed procedural protocol. 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.

The first step was to perform 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 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. A Knowledge Audit Table was used to enable notetaking for this phase (Fig 23). The probes for the KA phase were as follows:

a) **Past & Future.** Experts can figure out how a situation developed, and they can think into the future to see where the situation is going. Among other things, this can allow experts to head off problems before they develop.

- Is there a time when you walked into the middle of a situation and knew exactly how things got there and where they were headed?

(follow up)

- In this situation, how would you know this? What cues and strategies are you relying on?
- In what way would this be difficult for a less experienced person? What makes it hard to do?

b) **Big Picture.** Novices may only see bits and pieces. Experts are able to quickly build an understanding of the whole situation—the Big Picture view. This allows the expert to think about how different elements fit together and affect each other.

- Can you give me an example of what is important about the Big Picture for overtaking?
- What are the major elements you have to know and keep track of?

c) **Noticing.** Experts are able to detect cues and see meaningful patterns that less-experienced personnel may miss altogether. I know this happens all the time, but my guess is that the more experience you have, the more accurate your seemingly unusual judgments become.

- Have you had experiences where part of a situation just “popped” out at you; where you noticed things going on that others didn't catch? What is an example? What cues and strategies are you relying on? Were you right? Why (or why not)?
- Have you ever detected the wrong pattern, because of a false cue? Cues that are very similar, but lead to different situations?
- In what way would this be difficult for a less experienced person? What makes it hard to do?

d) **Job Smarts**. Experts learn how to combine procedures and work the task in the most efficient way possible. In seafaring, it is important not to waste time and resources and navigate with safety.

- When you do this task, are there ways of working smart or accomplishing more with less—that you have found especially useful? "How does this differ from what you did as a trainee pilot?"

e) **Opportunities/Improvising.** Experts are comfortable improvising—seeing what will work in this particular situation; they are able to shift directions to take advantage of opportunities.

- Can you think of an example when you have improvised in this task or noticed an opportunity to do something better?

f) **Self-Monitoring.** Experts are aware of their performance; they check how they are doing and make adjustments. Experts notice when their performance is not what it should be (this could be due to stress, fatigue, high workload, etc.) and are able to adjust so that the job gets done.

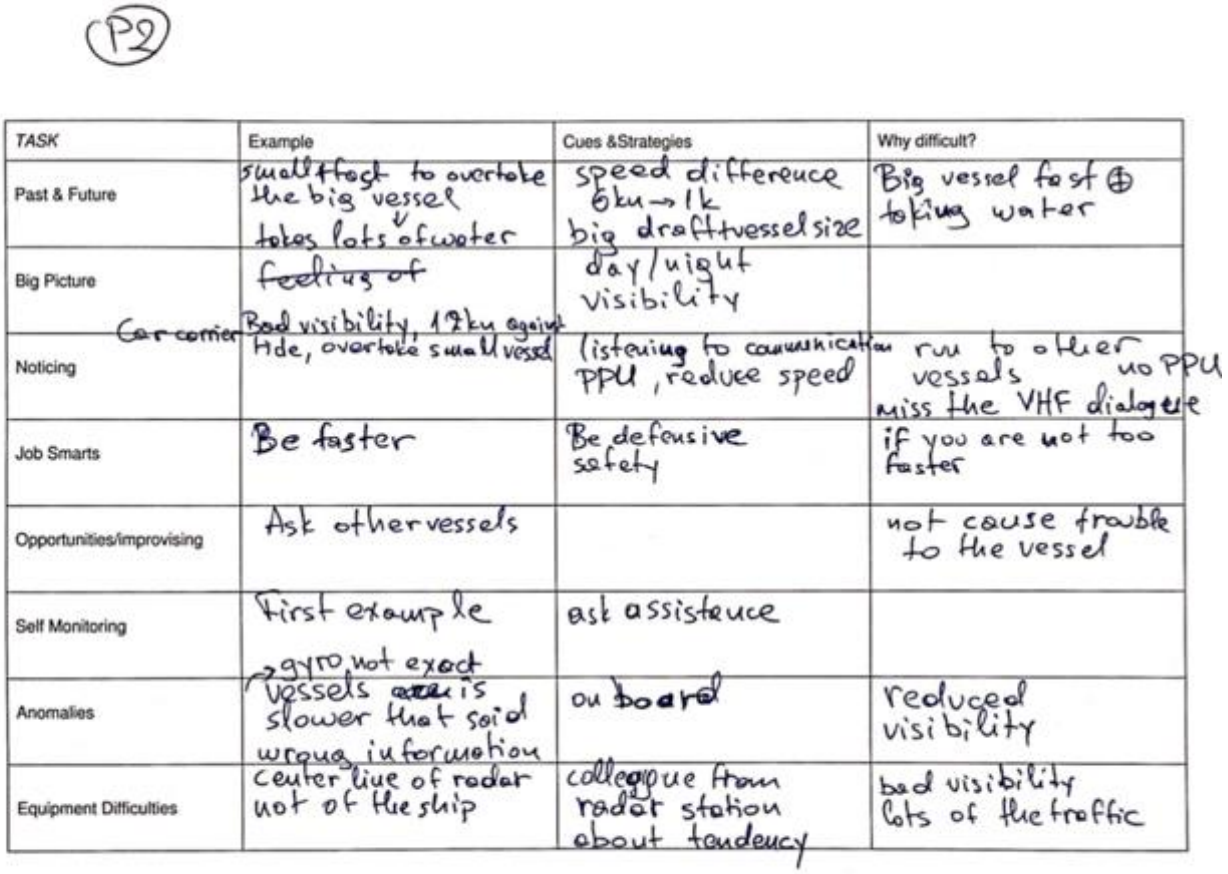
- Can you think of a time when you realized that you would need to change the way you were performing in order to get the job done?

g) **Anomalies.** Novices don't know what is typical, so they have a hard time identifying what is atypical. Experts can quickly spot unusual events and detect deviations. And, they are able to notice when something that ought to happen, doesn't.

- Can you describe an instance when you spotted a deviation from the norm, or knew something was amiss during a pilotage activity?

h) **Equipment Difficulties**. Equipment can sometimes mislead. Novices usually believe whatever the equipment tells them; they don't know when to be skeptical.

- Have there been times when the equipment (PPU, AIS, Radar, ECDIS) pointed in one direction, but your own judgment told you to do something else? Or when you had to rely on experience to avoid being led astray by the equipment?



P2

TASK	Example	Cues &Strategies	Why difficult?
Past & Future	small tfact to overtake the big vessel takes lots of water	speed difference 6kn → 1k big draft+vessel size	Big vessel fast ⊕ taking water
Big Picture	~~feeling of~~	day/night visibility	
Noticing	Car carrier Bad visibility, 17kn against tide, overtake small vessel	listening to communication PPU, reduce speed	run to other vessels no PPU miss the VHF dialogue
Job Smarts	Be faster	Be defensive safety	if you are not too faster
Opportunities/improvising	Ask other vessels		not cause trouble to the vessel
Self Monitoring	First example → gyro not exact	ask assistence	
Anomalies	vessels ~~[illegible]~~ is slower that said wrong information	on board	reduced visibility
Equipment Difficulties	center line of radar not of the ship	colleague from radar station about tendency	bad visibility lots of the traffic

Figure 23 Sample from the notetaking during the KA phase of the interviews for Participant 2

For the third phase of the Simulation Interview (SI), a scenario was created, 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. The author in collaboration with the corresponding pilot 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 (Figures 39 and 40).

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 (see Appendix C).

Scenario for the Simulation Interview.

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.

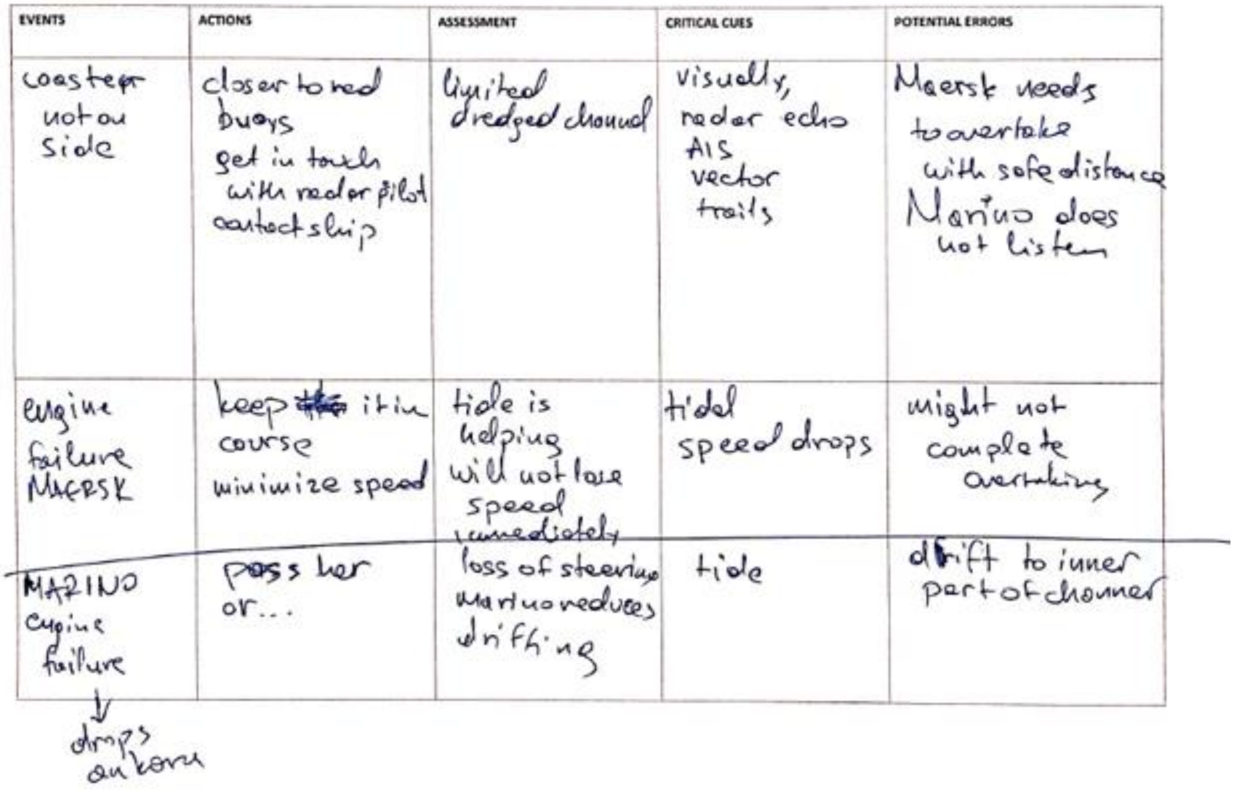
- Weather: T: 18-19^{o}C, wind at 17Km/h (3Bft) SW, gusts at 33Km/h(5Bft), visibility 15km, cloudy
- High tide 3.37m at 10:52 AM, Low tide 0.5m at 5:25 PM
- Current: 3.3 knots on the surface and 2.5 knots at a depth of 2m below mean low water level
- Time is 12:00

Table 1 Scenario for the Simulation Interview

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. The following prompts were also prepared to elicit information on major events during the SI interviews:

- What do you think is going on here? What is your assessment of the situation at this point in time?
- As the pilot that advises the master in this scenario, what actions, if any, would you take at this point in time?

- What pieces of information led you to this situation assessment and these actions?
    - What does this information/element mean to you? It helps you be aware of what?
    - Do you consider this information in relation to other elements or conditions?
- What sensors/instruments do you use to gather the necessary information?
- In what ways can the decision be difficult? What errors would an inexperienced person be likely to make in this situation?



EVENTS	ACTIONS	ASSESSMENT	CRITICAL CUES	POTENTIAL ERRORS
coaster not on side	closer to red buoys get in touch with radar pilot contact ship	limited dredged channel	visually, radar echo AIS vector trails	Maersk needs to overtake with safe distance Marino does not listen
engine failure MAERSK	keep ~~the~~ it in course minimize speed	tide is helping will not lose speed immediately	tidal speed drops	might not complete overtaking
MARINO engine failure	pass her or...	loss of steering Marino reduces drifting	tide	drift to inner part of channel

↓
drops ankors

Figure 24 Notes from the Simulation Interview

All interviews were conducted by the author 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 25 shows a diagram that summarizes the research activities of both studies and their outputs.

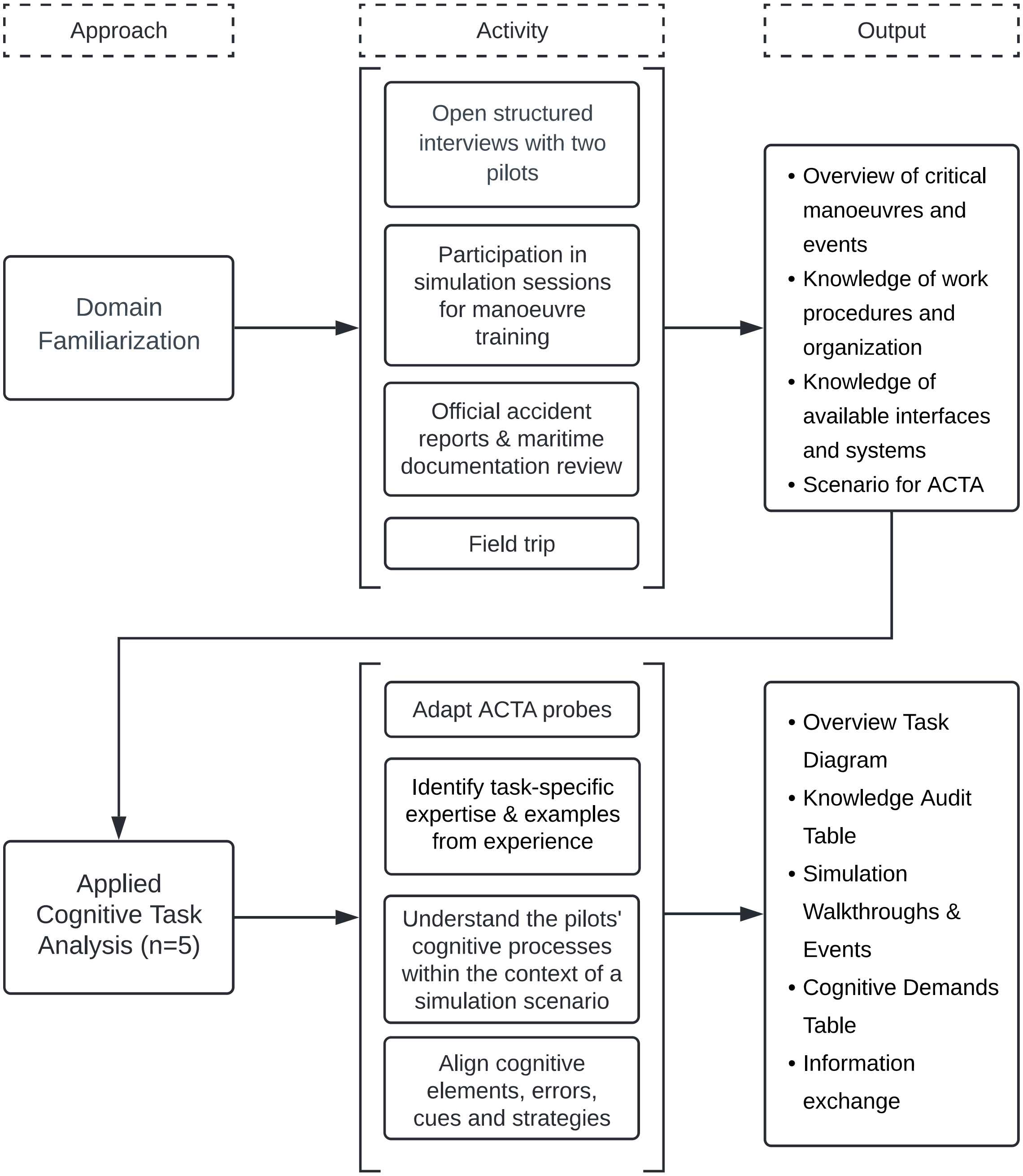
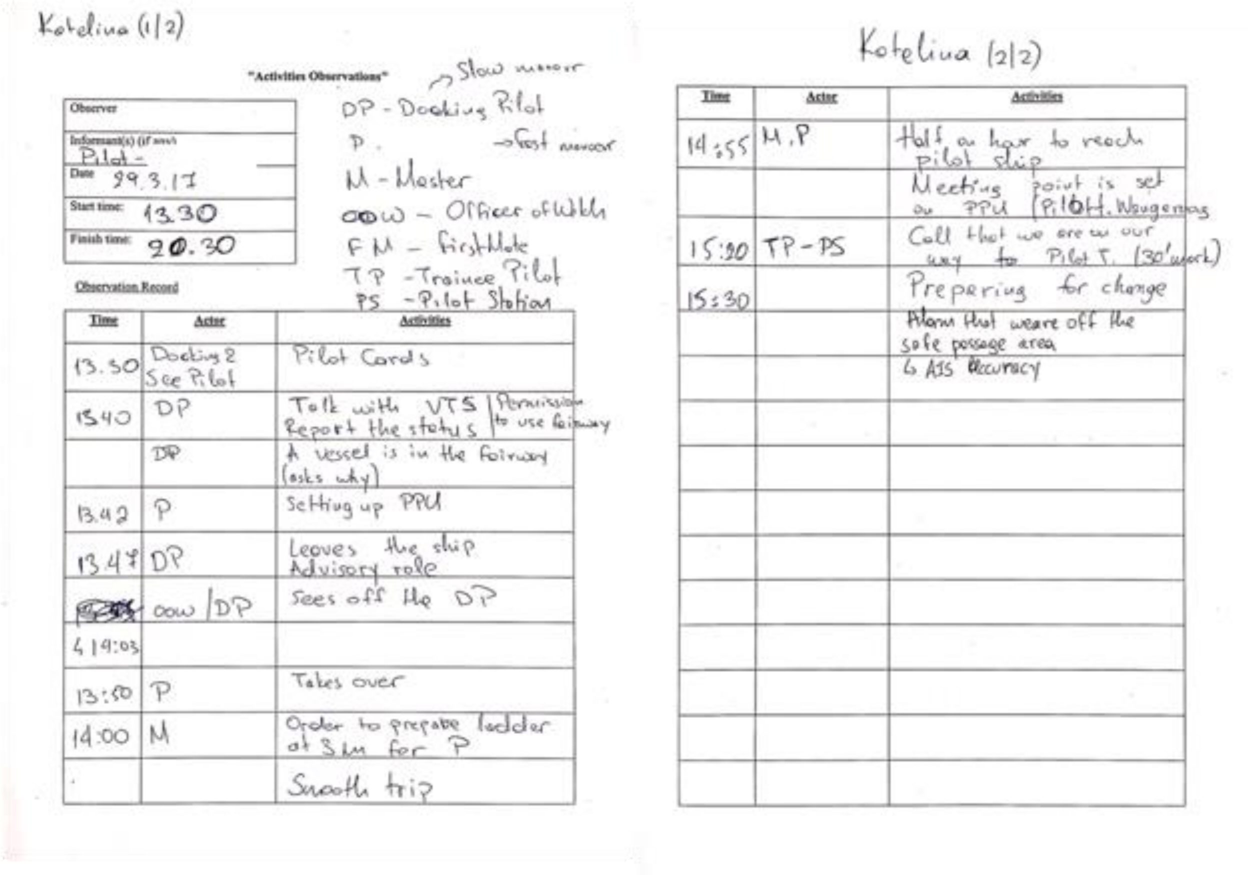


Figure 25 Research framework and methods of study 1 and study 2

4.4 Data analysis

The data 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.



Katelina (1|2)

"Activities Observations"

Observer	
Informant(s) (if any)	Pilot -
Date	29.3.17
Start time:	13.30
Finish time:	20.30

DP - Docking Pilot → Slow maneuver
P → fast maneuver
M - Master
OOW - Officer of Watch
FM - First Mate
TP - Trainee Pilot
PS - Pilot Station

Observation Record

Time	Actor	Activities
13.30	Docking 2 See Pilot	Pilot Cards
13.40	DP	Talk with VTS | Permission to use fairway Report the status
	DP	A vessel is in the fairway (asks why)
13.42	P	Setting up PPU
13.47	DP	Leaves the ship Advisory role
[illegible]	OOW / DP	Sees off the DP
↳ 14:03		
13:50	P	Takes over
14:00	M	Order to prepare ladder at 3m for P
		Smooth trip

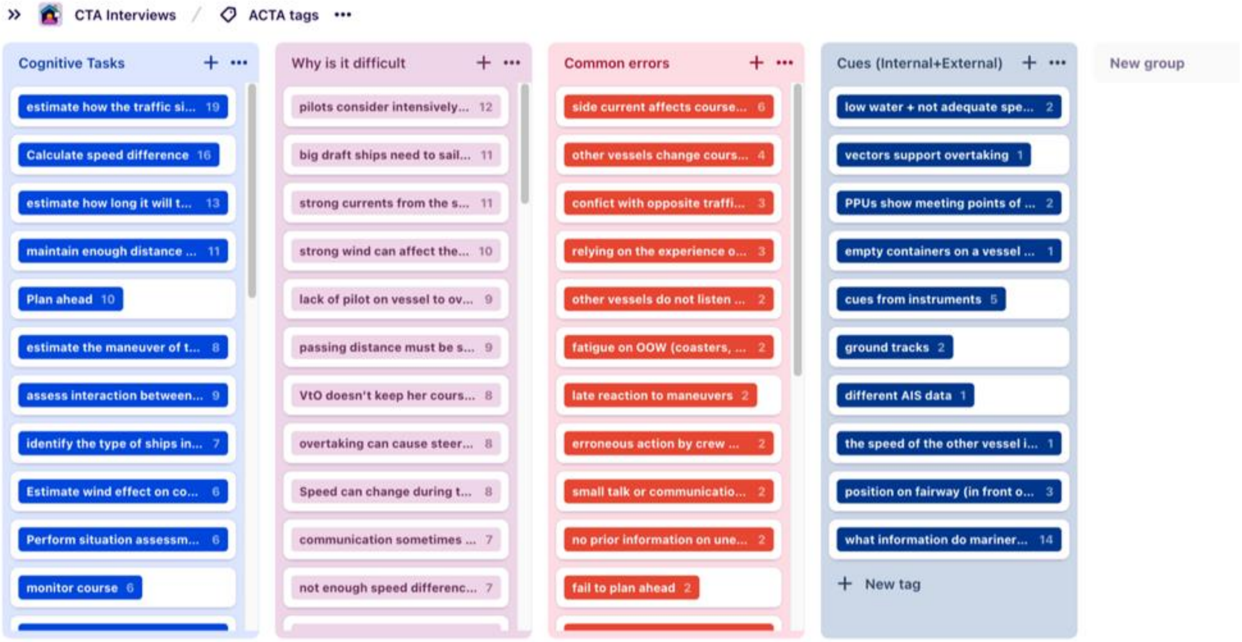
Katelina (2|2)

Time	Actor	Activities
14:55	M, P	Half an hour to reach pilot ship
		Meeting point is set on PPU (PilotH. Waugennas
15:20	TP - PS	Call that we are on our way to Pilot T. (30' work)
15:30		Preparing for change
		Alarm that we are off the safe passage area
		↳ AIS Accuracy

Figure 26 The activity recording from the outbound trip onboard of Katelina.

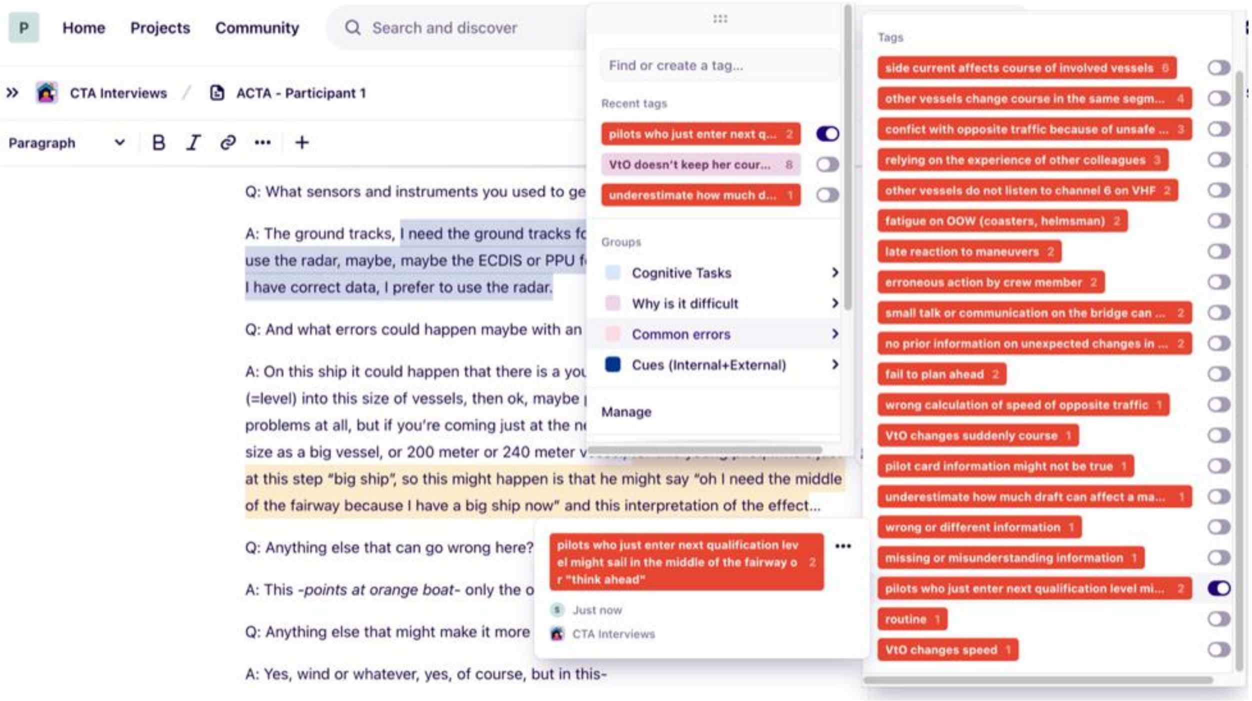
The audio recordings were used for the actual transcription of everything said and the video recordings were used complementary to describe what vessels or areas the participant was pointing at during the SI. The content of the video data was added to the same transcription as the voice recording, resulting in one single transcription per participant.

The transcripts were then imported in the 'Dovetail App' (2022) to perform content analysis. First, a list of concepts was defined that facilitated the analysis based on the derived insights from the 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, the author 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 the specific study, the author combined both a deductive and inductive approach to coding. Even though the process was initiated deductively with a set of concepts, additional concepts were inductively created the author developed codes that did not fit within the initial concepts. Finally, the concepts and codes were iteratively reviewed and were compiled in the Cognitive Demands Table (CDT) that consolidates and synthesizes the data.



Cognitive Tasks	Why is it difficult	Common errors	Cues (Internal+External)
estimate how the traffic si... 19	pilots consider intensively... 12	side current affects course... 6	low water + not adequate spe... 2
Calculate speed difference 16	big draft ships need to sail... 11	other vessels change cours... 4	vectors support overtaking 1
estimate how long it will t... 13	strong currents from the s... 11	confict with opposite traffi... 3	PPUs show meeting points of ... 2
maintain enough distance ... 11	strong wind can affect the... 10	relying on the experience o... 3	empty containers on a vessel ... 1
Plan ahead 10	lack of pilot on vessel to ov... 9	other vessels do not listen ... 2	cues from instruments 5
estimate the maneuver of t... 8	passing distance must be s... 9	fatigue on OOW (coasters, ... 2	ground tracks 2
assess interaction between... 9	VtO doesn't keep her cours... 8	late reaction to maneuvers 2	different AIS data 1
identify the type of ships in... 7	overtaking can cause steer... 8	erroneous action by crew ... 2	the speed of the other vessel i... 1
Estimate wind effect on co... 6	Speed can change during t... 8	small talk or communicatio... 2	position on fairway (in front o... 3
Perform situation assessm... 6	communication sometimes ... 7	no prior information on une... 2	what information do mariner... 14
monitor course 6	not enough speed differenc... 7	fail to plan ahead 2	+ New tag

Figure 27 The resulting themes and tags after performing thematic analysis on five ACTA interviews in the Dovetail App environment. Author's image.



Q: What sensors and instruments you used to ge

A: The ground tracks, I need the ground tracks fo
use the radar, maybe, maybe the ECDIS or PPU f
I have correct data, I prefer to use the radar.

Q: And what errors could happen maybe with an

A: On this ship it could happen that there is a you
(=level) into this size of vessels, then ok, maybe
problems at all, but if you're coming just at the n
size as a big vessel, or 200 meter or 240 meter v
at this step "big ship", so this might happen is that he might say "oh I need the middle
of the fairway because I have a big ship now" and this interpretation of the effect...

Q: Anything else that can go wrong here?

A: This *-points at orange boat-* only the o

Q: Anything else that might make it more

A: Yes, wind or whatever, yes, of course, but in this-

Figure 28 Tags on the transcribed text from the interview of participant 1 in the Dovetail App environment

4.5 Results

Results are presented in the following sections as follows. First, some of the observations from the field trip and the visit to the pilot station during the domain familiarization phase are presented. Second, the Overview Task Diagram follows with illustrative responses by the participants to demonstrate the findings. Third, the results from the Knowledge Audit phase and the Simulation Summary are included. Lastly, the Cognitive Demands Table shows an analytical summary of the cognitive challenges identified across the sample as a whole. For each of these cognitive challenges, 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 are identified.

It should be noted that Figures 4 to 14 in subchapter 2.4 Ship Bridge Systems are all images taken by the author during the field trip.

4.5.1 The Weser/Jade 2 pilot station

Prior to conducting the explorative interviews, the corresponding pilot provided a tour of the premises and main work areas of the Weser/Jade 2 pilot station. Rooms with maps, prints of daily tidal forecasts, time of low tide and high tide, planning boards (inbound and outbound vessels), the board with the pilots on duty and their whereabouts and the workstation of the radar pilot that assists the pilots that are on board were among the observed areas. Figures 29 to 32 show aspects of the areas and some artifacts that are used in the pilot station to facilitate daily work.

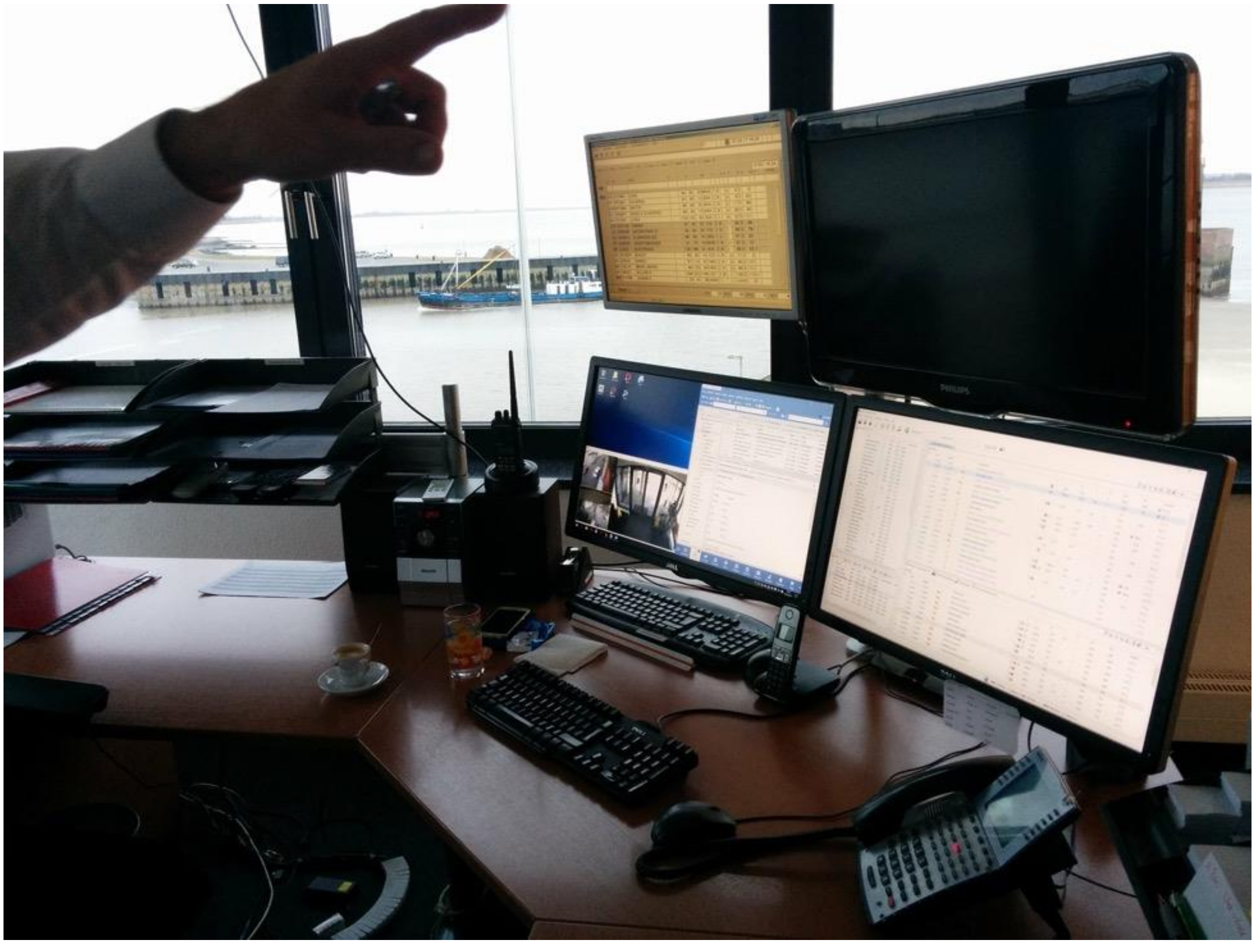


Figure 29 The workstation of the radar pilot in shore. Author's image.

Figure 30 The status of the pilots of the station (in land, busy, on radar duty, inshore pilot station, on call, etc). Author's image.

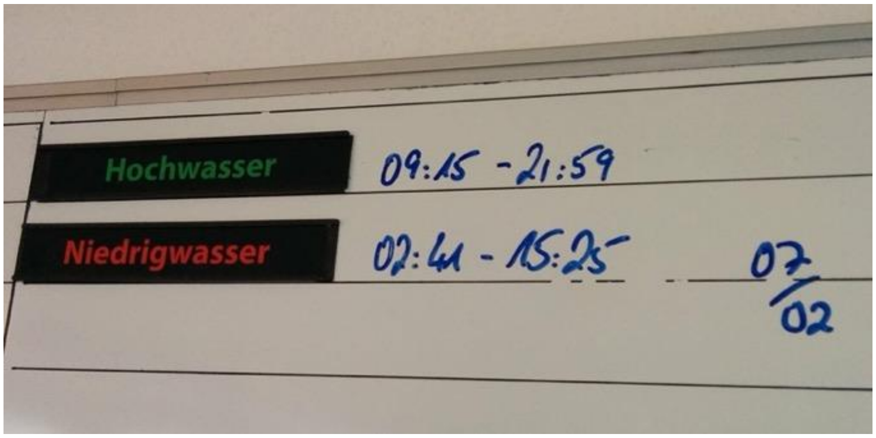


Figure 31 High tide and Low tide time indicators on the day of the visit. Author's image.

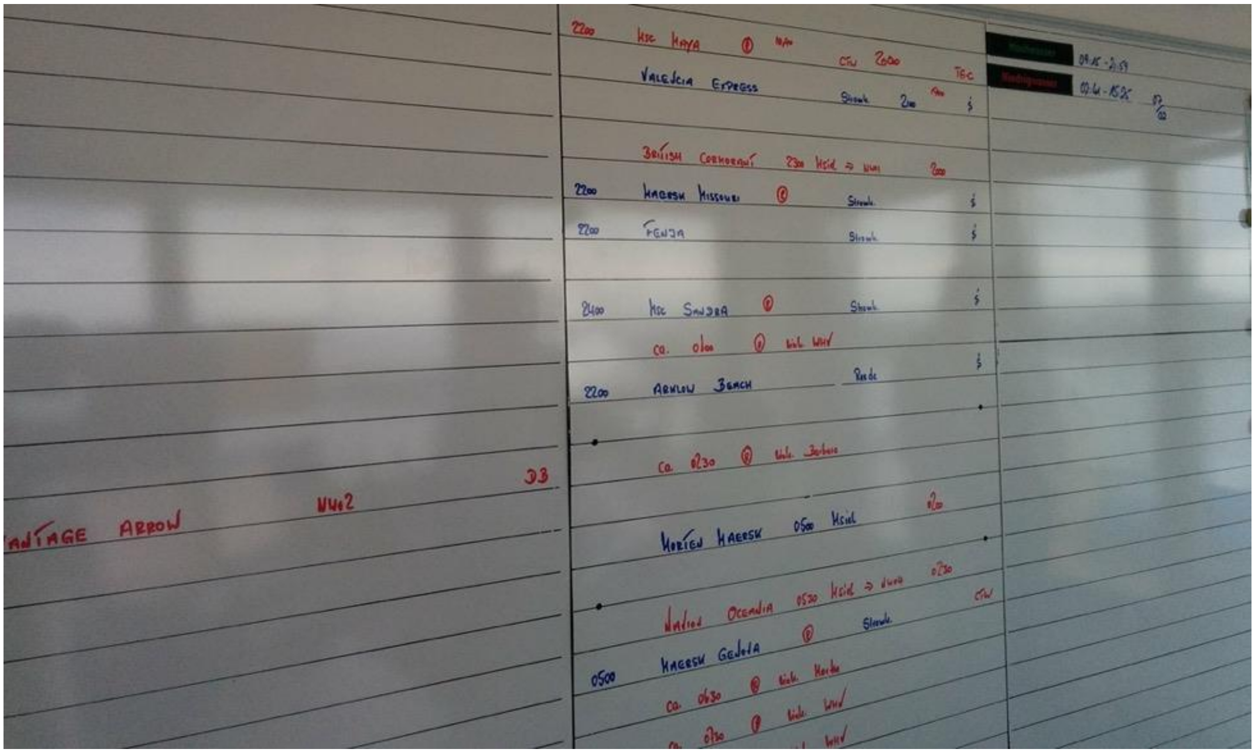


Figure 32 The scheduled arrivals and departures of vessels that will need pilotage service from the station. Author's image.

4.5.2 Observation of pilotage

The author was fortunate to observe the bridge team performing an overtaking manoeuvre during the second voyage of the field trip in the German Bight fairway (Fig 37). The 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 the boarded 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 Figure 22). 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.

Figure 33 The officer on watch performing his duties on the bridge of the outbound vessel. Author's image.

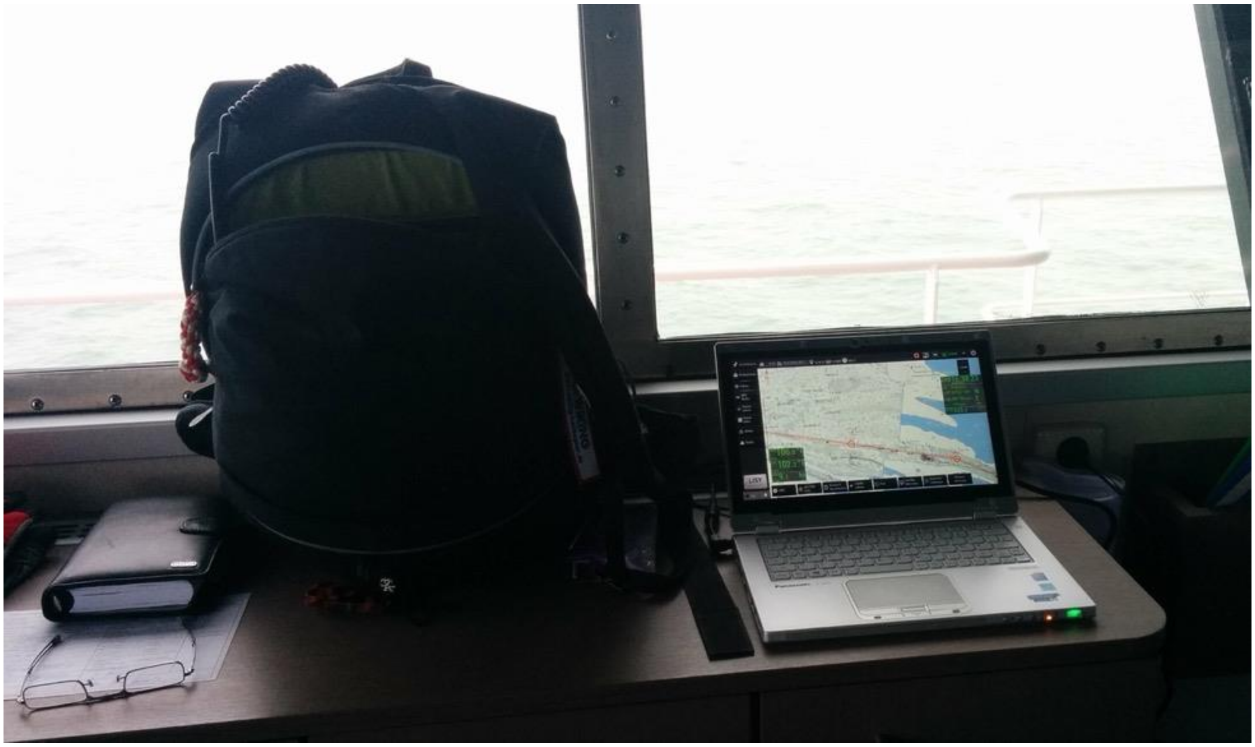


Figure 34 The PPU setup of the pilot on board of the vessel of the first trip

Figure 35 EMS DUNDEE: The officer on watch during the tour of the ship bridge instruments. The MFD for the interface of the engine system is turned on in the propulsion control mode. Author's image.

Figure 36 The pilot explains how the PPU can be used to observe other ships' courses. The meeting points on the display indicate passing and overtaking manoeuvres. Author's image.

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.

The activity recording was done mainly with pen and paper since the observed task was reasonably paced with few points of interest over a period of time. There was also video recording of specific activities. Both pilots and crews were very helpful and cooperative during the observations and enabled the procedure by explaining on camera the instruments on the ship bridge and their functionalities (Figures 33-36). To enable notetaking, an observation guide was created that was used as seen in Figure 26. Appendix A includes the full activities analysis, where the activity timeline is formatted in a structured observation guide.

Figure 37 During the overtaking of a 70m long oil tanker vessel in the fairway in the inbound trip to the port of Bremerhaven.

4.5.3 Overview Task Diagram

The replies from all 5 pilots have been compiled into one single Overview Task Diagram (OTD) as depicted in Figure 38. Examples of participants' responses illustrating these themes are evidenced in Table 2. The OTD consists of six steps and reflects the consensus among participants about the sequence of the cognitive tasks performed during overtaking. Four 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.

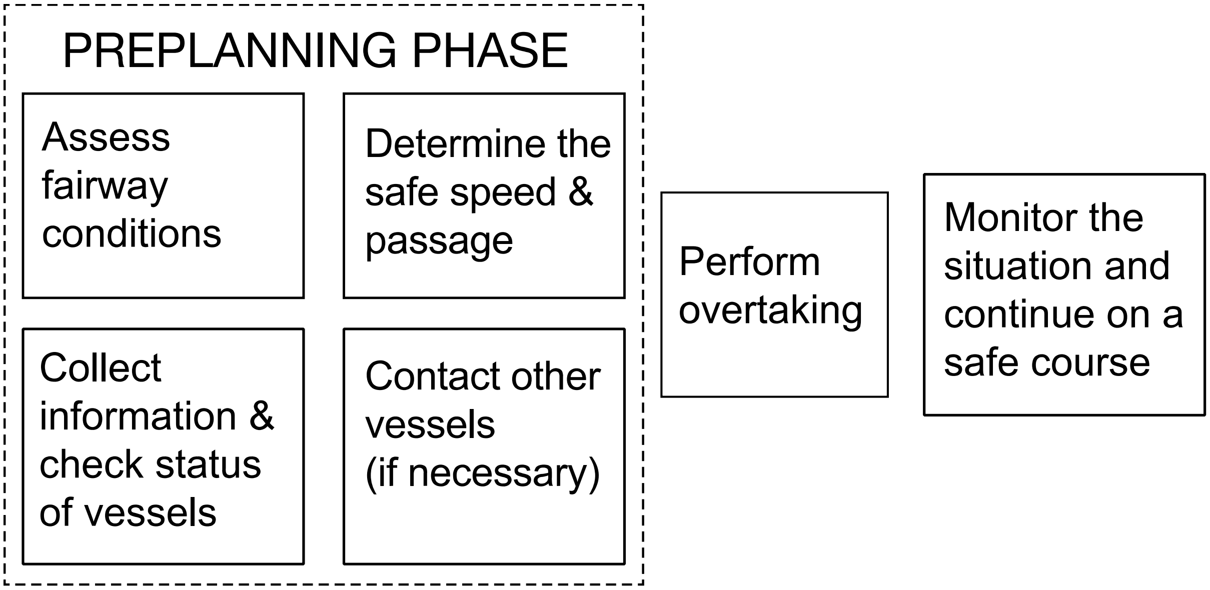


Figure 38 : Overview Task Diagram illustrating the stages associated with pilots' decision making when overtaking in a fairway.

Task Diagram Stage	Example of participant response
Assess fairway conditions	“I have to clarify if the fairway is free to do this manoeuvre when I check the traffic situation” (P5) “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.” (P3)
Collect information and check status of vessels	“the first information I have for my own ship, size of my own ship, draft of my own ship” (P2) “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” (P4) “an overview about the equipment. What kind of… Is he on autopilot, is he on manual steering, what kind of rudder” (P3)
Determine the safe speed and passage	“enough room, enough speed, I have to increase the speed to overtake somebody, or the other one has to slow down…” (P1) “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.” (P2)
Contact other vessels (if necessary)	“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.” (P1) “maybe I will ask also the one who is to be overtaken if he can help me and reduce for a short while” (P2)
Perform overtaking	“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” (P2) “when I have an agreement to overtake I start my manoeuvre with of course good seamanship, overtaking in safe distance” (P5)
Monitor the situation and continue on a safe course	“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.” (P2)

	"I'm focusing more what is happening later on with the ship I am passing quite fast" (P3) "I really have to monitor this meeting point all the way…till the overtaking manoeuvre is over." (P4)

Table 2 Examples of participants' responses for the Overview Task Diagram stage. Participant number is in parentheses next to each response.

4.5.4 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 aggregately reflected in the steps *Assess fairway conditions*, *Collect information and check status of vessels* and *Determine the safe speed and passage* as mentioned in the 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 via which 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. The 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. The full list of responses are available in the Appendix D.

Probe	Number of responses	Example of participant response
Past and Future	7	“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) “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)
Big Picture	7	“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)
Noticing	13	“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)
Job smarts	7	“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)
Opportunities & Improvising	6	“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)
Self-monitoring	9	“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)

Anomalies	5	"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)
Equipment Difficulties	6	"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)

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.

4.5.5 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 (Figure 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 considering 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."

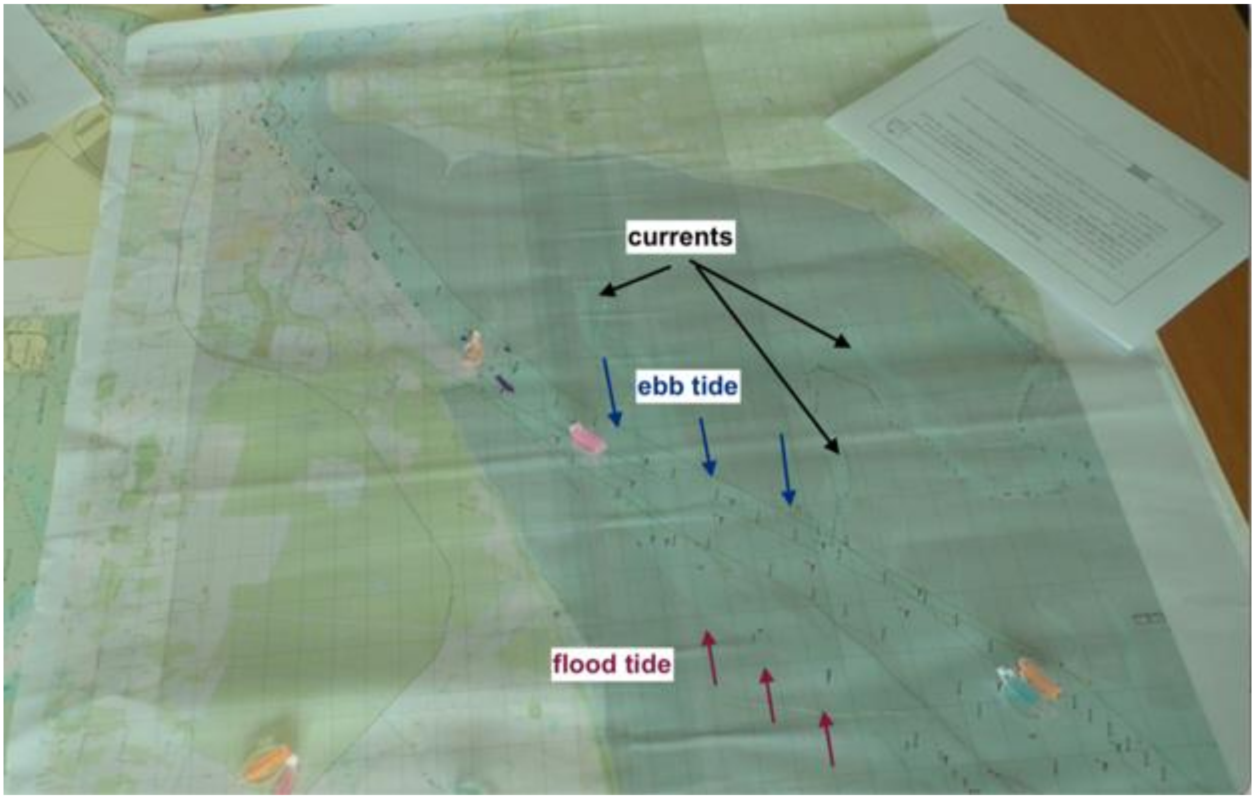


Figure 39 An annotated video capture image from a Simulation Interview on a scenario. Annotations were made by analysing transcripts and video recording of the interview. The annotations show how the local environmental conditions (tide, current) affect the vessels that sail in the specific segment.

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 B includes the simulation interview prompts that were used during the SI phase. Appendix E includes indicative examples from the SI content analysis.

4.5.6 Cognitive Demands Table

The CDT summarizes the final analysis of the 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

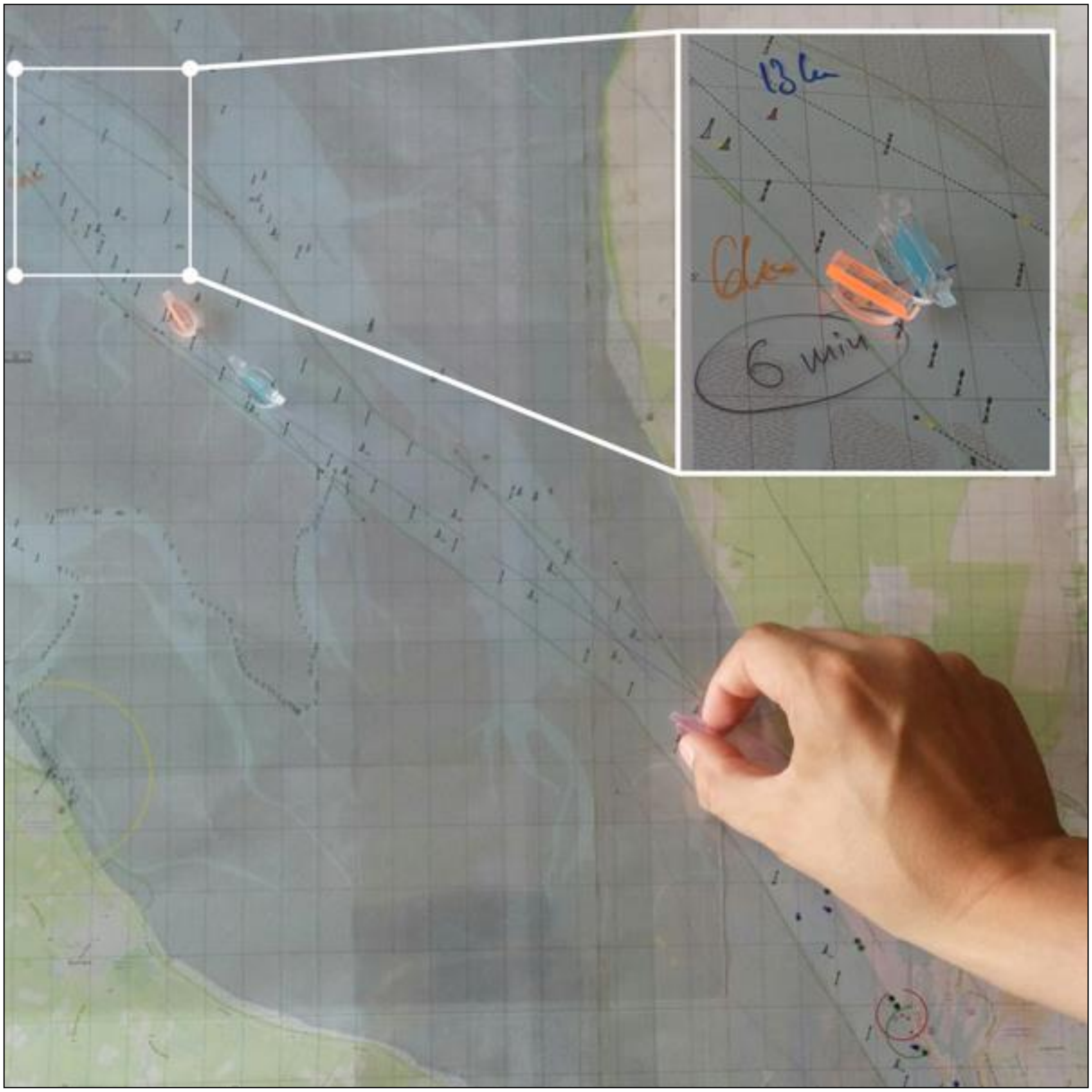


Figure 40 A participant demonstrates how and when will the overtaking occur in the specific scenario with the help of the low-fidelity simulation material.

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 as seen in Table 4 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.

Cognitive challenges	• Why difficult	• Common errors	• Strategies & Practices	• Cues + Sources
(1) Calculate the speed difference with the forward vessel	• Speed limits in fairway segments • Equipment and manoeuvring limitations • Environmental effects on speed (wind, current, tide) • Involved vessels might need to slow down to use tugs • River seabed affects the speed • Banking effects on speed • Not enough speed difference can cause suction	• Speed difference is less than 3-4kn and overtaking takes longer than anticipated • Small ships are likely to be most affected by suction • Passing with slow speed can be dangerous for either vessel	• Reliance on tacit knowledge – know how much speed difference is safe in these conditions • Change speed to achieve good speed difference • Apply corrective helm	• Speed of both vessels • Fairway status • Environmental conditions • Tide, current • Manoeuvrability characteristics
(2) Determine if there is enough room to initiate overtaking	• Restricted fairway width does not allow for wrong turns • HI with the other vessel • Draft/slack water might cause bank effects • Possible opposite traffic • Wind might cause heading changes and leeway • Navigation in traffic separation schemes	• Underestimate hydrodynamic and wind effects • Inexperience with certain vessel types • May not request cooperation from VtO • Miscalculate how much space the vessel takes when it sails at an angle • Ignore course change during manoeuvre execution	• Request assistance from VtO/radar pilot/VTS • Action from both vessels • Increase distance between vessels • Reduce the speed to improve the conditions • Make exact and timely course changes •	• Fairway width, depth • Own vessel information • VtO vessel information • AIS • VTS • Radar pilot

Cognitive challenges	• Why difficult	• Common errors	• Strategies & Practices	• Cues + Sources
(3) Estimate how the traffic situation will evolve	• High traffic volume • Other vessels might block the fairway by turning 180o in front of the container terminal • Deep draft vessels need to sail close to the middle of the fairway • Tugs will need to approach • Strong winds will cause vessels to navigate with leeway •	• Focus on current traffic situation and ignore future working situations • Overtake with a limited time frame • Underestimate weather effect (Bad visibility, strong winds) • Lack of communication • Ignore speed limits in calculations • Ignore types and status of other vessels • Start overtaking a vessel that will stop at the container terminal	• Consider if there is another working situation right after overtaking (ie use of tugs, another passing) • Collaborate with other vessel radar pilot /VTS • Get regular traffic status update • Avoid overtaking on time pressure • Perform overtaking fast • Avoid overtaking big vessels with a big vessel to avoid strong S2S interaction • Use all available informational resources •	• Speed of opposite traffic • Radar • VTS • Radar pilot • Status of container terminal and other important fairway points • Status of all vessels (ETA, destination, Size, position on certain fairway segments • Speed limits •
(4) Communicate effectively with other ship and other actors	• Communication is not necessary to perform overtaking • Language barrier between crews • Too much communication on VHF channel or small talk on the bridge can distract inexperienced mariners • Master might be absent/busy	• Communication is late and leads to unavoidable situations • VHF is set on the wrong channel or the volume is off • Inexperienced crew might not share proper information	• Inform other traffic and VTS about intentions during planning • Listen to communication between vessels on dedicated VHF channel • Try communication via VTS if the other vessel does not respond • Use other sources to check unclear input (ie additional	• VHF • VTS • Radar pilot • Mobile phones •

Cognitive challenges	• Why difficult	• Common errors	• Strategies & Practices	• Cues + Sources
			radar guidance from shore)	
(5) Combine information and cues from various sources	• Mixed equipment that does not work well together • Equipment might not be updated or calibrated • Missing information from screens • Some vessels sail without AIS • Sailing boats or smaller traffic might not appear on radar • Weather conditions and darkness might not allow look out • Complete or partial failure of equipment	• Excessive focus on certain instruments • Neglect cross-checking • Neglect observing surroundings • Use wrong range maker • Possible confusion over a cue • Pilot is unaware of equipment functioning at less than 100% (bow thruster, propeller, rudder)	• Rely on primary information input • Verify cues with input from other sources • Continuously monitor surroundings (eyes, binoculars) • Ask crew members to monitor an information source • Use tacit knowledge for structural elements (buoys, etc) • Adjust radar • Verify with crew status of equipment •	• Speed indicator, rudder indicator, noise, • VHF • AIS data • Visual information (radar ECDIS, PPU, gyro compass, GPS) • COG, SOG, heading • Leading lights, distance to the buoys •
(6) Collaborate with the other mariners (pilot, master, crew members)	• The experience of other mariners is often unknown (In terms of judgment, decision making skills, navigation skills and exposure to difficult s) • VtO is without a pilot and cooperation is uncertain • Language barrier • Wrong or different information	• Communicating incorrect information • Pilot has not full picture of vessel status • Proceed with overtaking when VtO master/pilot is unresponsive • A crew member misunderstands a command by the pilot •	• Communicate with involved vessels • Verify information and/or ask for assistance from VtO/radar pilot/VTS • Decide if own confidence to the other pilot/master is adequate (Trust own gut) • Continuously check the status of the overtaken vessel	• Input from crew /VTS/ Radar pilot / other vessel •

Cognitive challenges	• Why difficult	• Common errors	• Strategies & Practices	• Cues + Sources
	• Vessels might decline to enable the (time order in container terminal, previous bad experience or bad seamanship) •		• Support colleagues with less experience with tacit knowledge and insight	
(7) Determine the effect of current	• Strong side currents can affect course and speed • Combination of strong wind and current can be dangerous • Cause ships to sail in wrong side of fairway • Ships might not react anymore due to current effect • Vessels that do not sail regularly in the area are unaware of the current effect	• Not knowing when to react • Neglect to consider the current in speed calculation • Pilot is unaware of unexpected changes in equipment	• Change the speed in advance to maintain a safe speed • Give notice to other vessels about currents • Be extra cautious • Use all resources to stay in course	• Current (force, direction) • Tide • Speed
(8) Determine the intensity of the hydrodynamic effects	• Hydrodynamic interaction is noticeable in overtaking because of duration of passing • Changing the speed might result in course changes and loss of control for both vessels • Smaller vessels gain speed when overtaken by big vessels • The smaller vessel may change course towards	• Proceeding at full sea speed increases the risk of an uncontrolled shear • Inappropriate speed in relation to the depth of water might lead to loss of control • Fail to treat each as unique (different ships, conditions and ship bridge crew (human factor))	• Perform overtaking as fast as possible • Continuously monitor the status of overtaken vessel • Reduce speed in good time • Sufficient contingent power available to aid the rudder if necessary • Maintain a safe speed and safe distance • Cooperate closely with overtaken vessel	• Under keel clearance, hull, draught, trim in relation to the available depth of navigable water • Engine power, rudder type • Loading condition of vessel vessel has a list or is upright

Cognitive challenges	• Why difficult	• Common errors	• Strategies & Practices	• Cues + Sources
	the path of the large vessel (suction) • More critical when a smaller vessel is passing a larger vessel • Deep draught vessels have a slower response to speed reduction • Possible trapping situation for overtaking vessel once it is past the VtO •	• Focus on speed difference and ignore the effect of a deep draft in the interaction • Hydrodynamic pressure zone around the vessel might extend further than assumed •	• Navigate with leeway to avoid suction •	• Speed of vessels • Distance between vessels • Tide, current • Environmental conditions
(9) Calculate duration of overtaking	• Own vessel speed might drop • The riverbed can change the speed • Large vessels are limited in their actions in narrow channels • The hydrodynamic effects will be greater while overtaking lasts • Might meet with opposite traffic during unsafe circumstances • Other traffic might be affected (time order, course changes)	• Underestimate hydrodynamic effects (speed reduction, meeting points) • Lack of resources for speed modification during • Overtake large vessel with large vessel • Underestimate environmental and weather influence	• Avoid affecting the ETA and status of involved vessels • Communicate with involved vessels to get confirmation, ask them to maintain speed and enable faster overtaking • Maintain smooth traffic conditions	• Speed • Speed difference • Meeting point • Size and draft • Tide level of the river • Distance to other vessel •
(10) Maintain a safe speed	• Speed limits • Interaction effects last longer	• Reducing speed during overtaking will cause suction	• Ask other vessels to reduce speed or increase distance if possible from vessel / bank	• Noise and vibration as indications of unsafe speed

Cognitive challenges	• **Why difficult**	• **Common errors**	• **Strategies & Practices**	• **Cues + Sources**
	• Riverbed and slack water can affect the speed • Speed changes during the manoeuvre can cause problems • Inadequate speed difference during overtaking can lead to loss of control for both vessels •	• Underestimate the speed reduction because of hydrodynamic effects •	• Avoid reaching the engine max speed	• Echo sounder (engine parameters) •
(11) Maintain a safe passing distance	• Limited fairway width • Inadequate distance can lead to quick loss of control to both vessels • Wind, tidal, current effects need to be calculated • Other vessels might not feel the effects the same or act like they should • Steering tendencies can affect the manoeuvre • Opposite traffic might further restrict the available space • Dense fog can limit visual range at 40-50 m •	• Have a small distance between vessels • Inadequate distance to a large vessel • Overtaking a large vessel with a smaller vessel will cause suction and make control difficult • Ignore opposite traffic •	• Watch for waves that might occur on one side of the vessel (means the vessel is close to shallow water) • Hear to fog signals • Maximize distance to other vessel by going more to port as overtaking vessel • Low draft vessels can go a bit outside the dredged channel to increase the distance between ships • Continuously monitor distance • Avoid overtaking large vessels with smaller vessels • Communicate immediately if distance gets unsafe	• UKC • Distance to shore • Distance to buoy line • Distance to other vessels • Wind (hear, “feel” it) • Tide • Current • Total fairway width, • Depth • Steering tendencies

Cognitive challenges	• Why difficult	• Common errors	• Strategies & Practices	• Cues + Sources
			• Adjust the course to counter the wind effect • More rudder for a few minutes for wind effect	
(12) Plan ahead	• Traffic evolution is not always predictable • Use of tugs means speed reduction and possible blocking of traffic • Future opposite traffic with deep draft vessel might block the way • Might need notice for the engine to calm down in container terminal • Mariners with little or no experience might not be able to predict a local situation development •	• Overtake when there is a course change • Fail to reduce speed early enough for taking tugs • Neglect checking updates on status of other vessels • Fail to think of “what if” traffic scenarios • Unattendance by a mariner on the bridge •	• When the manoeuvre is complete, consider it as another working situation • Foresee possible scenarios before initiating overtaking (ie meeting with opposite traffic immediately after the manoeuvre is complete, change of course for an involved vessel) • Complete overtaking in good time to be clear for a future situation • Listen to communication on the dedicated VHF channel • Check the meeting points on the PPU • Initiate contact with colleagues to mitigate potential risks •	• ETA, final destination • VTS/VHF (inter-ship communication) /Radar pilot • PPU for passing points with other vessels

Table 4 The Cognitive Demands Table

4.5.7 Communication

Figure 41 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.

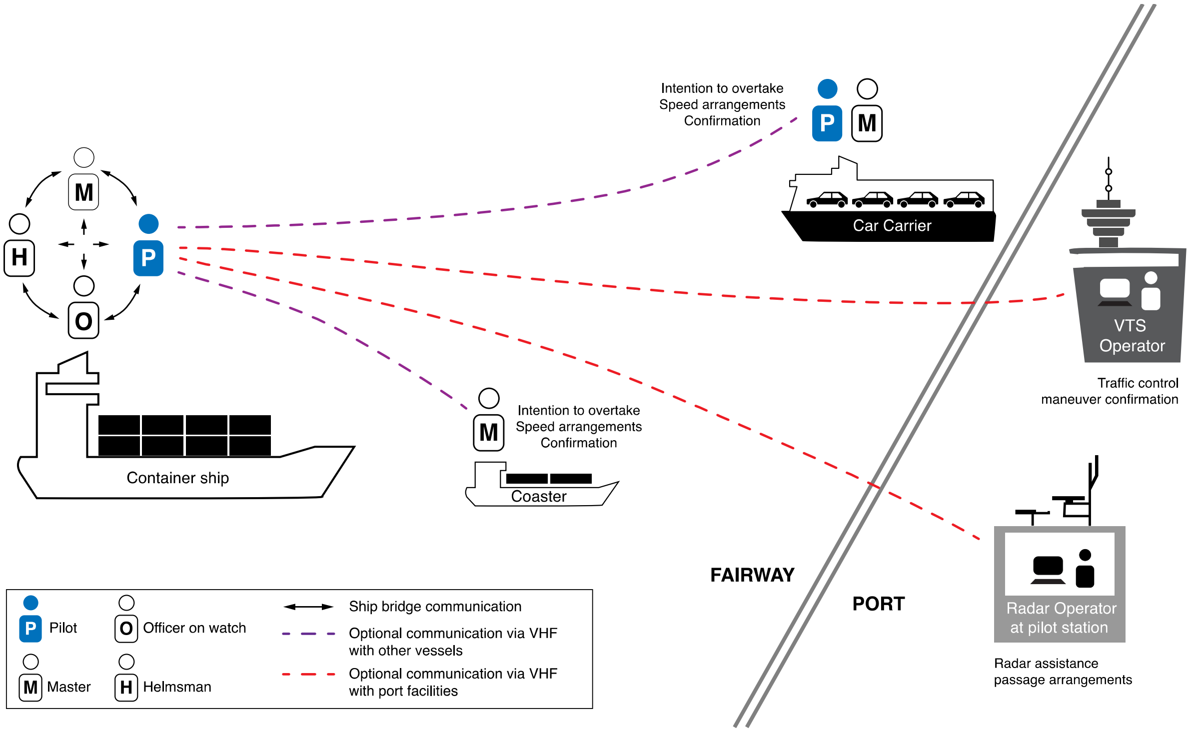


Figure 41 Information exchange before and during overtaking based on the scenario used in the simulation interview

4.6 Discussion

The present study aimed to identify the cognitive challenges of sea pilots during overtaking manoeuvres in restricted waterways. To reach this goal, ACTA interviews were employed in combination with findings from observations and related domain familiarization activities. The approach helped 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, twelve different cognitive challenges were identified that are relevant to the safety and effectiveness of the overtaking manoeuvre. The tacit knowledge, strategies, common errors and experience aspects that are relative to the cognitive challenges have been also described.

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.

4.6.1 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 the 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.

4.6.2 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, as suggested. These findings align with what Klein proposes in the RPD model and 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, the 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'.* The 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.

4.6.3 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; Yuan et al. 2015; Vantorre et al. 2017; 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.

4.6.4 Communication

Responses from the participants of this study as well as data from the 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.

The 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. The 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 the 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 this 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 2007).

Figure 42: A GPS device onboard of the outbound trip vessel set in Channel 6 for communication activities. Author's image.

The lack of communication between vessels in close proximity can result in ambiguity and increase the likelihood of an incident (Australian Maritime Safety Authority (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 pilotage operations (Ernstsen and Nazir 2018) and have revealed the high percentage of human error due to failure in communication during navigation in narrow waters (Sánchez-Beaskoetxea et al. 2021; Aydin 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 the findings of this study and highlight that pilotage 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 the domain familiarisation and ACTA 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 (Fig3). The 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 pilotage 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 the presented results. Therefore, the current pilotage practice paradigm, where pilots do not rely on explicit procedure but anticipate the future course in the form of absorbed coping (Dreyfus 1999), could explain the communication habits of pilots.

4.6.5 Planning and Foresight

The 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 pilotage (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 her 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). The 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.'*

4.6.6 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 (Hockey et al. 2003; Chauvin et al. 2013; Øvergård et al. 2015; Cordon et al. 2017). In this 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. The 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, the 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, the findings for causes for SA failure in pilotage have been reviewed. 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 stern part of a vessel, but that was wrong. That was just a dredger'.*

4.7 Limitations

The ACTA interviews proved to be a valuable method for the scope of this study, as they provided in-depth insights of pilots' decision-making activities during overtaking. Nevertheless, some limitations 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 the 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.

4.8 Practical Implications

Information about cognitive challenges derived through ACTA can inform design specifications of the workplace and operating procedures. The CDT provides the input needed to determine which information is required for supporting the task of overtaking. For instance, understanding the connection between Under Keel Clearance (UKC) and other factors all the way to the pilot's projection of how intense the hydrodynamic effects will be, may provide insight into the design of PPUs and other bridge instruments. 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 chapter may help to better describe and understand maritime pilotage accidents or incidents.

The ACTA methodology has the advantage of providing a structured way to gather and organize a large amount of diverse data. Creating the Task Diagram, Knowledge Audit Table, and Cognitive Demands Table helped in synthesizing 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).

Chapter 5 Factors influencing decisions making for safe overtaking

5.1 Introduction

In the previous chapter, the cognitive challenges of pilots during overtaking were identified and analysed. When mariners decide to perform a deviation of from the planned route, such as an overtaking manoeuvre, they take into consideration several factors. Some factors remain unchanged and are not modified during a manoeuvre, i.e. the draught of the vessel, the fairway width, etc. However, many of these factors are dynamic, such as speed, course, traffic, and more. Mariners are called to observe these factors, because any changes in their status can affect or even destroy the manoeuvre. The results of the ACTA study also indicated that alterations to some factors can result in changes in other factors, cost the mariners a lot of necessary resources for the manoeuvre and may compromise the safety of overtaking.

This chapter presents a study that identifies the factors influencing the pilots in their decision to overtake with safety. It also and investigates the interrelationships and any co-dependency between them. To achieve this, a participatory modelling approach with pilots was used for the same case study of overtaking in Bremerhaven. Specifically, Fuzzy Cognitive Mapping (FCM) techniques were applied to model the factors and their interconnectedness that contribute to safe overtaking based on the expert opinions of four sea pilots. The study focused on illustrating how FCMs can make the tacit knowledge of safe overtaking from individual sea pilots explicit to themselves and each other. The logic and mechanisms of FCMs can integrate information obtained from various participants and reveal the relationships between the factors that affect overtaking manoeuvres and the overall goal of navigation. The produced FCM consists of 38 factors and 82 connections that were validated with a different group of three expert sea pilots.

The results of this study contribute to the following research questions:

1. RQ1: While navigating in confined waters, how do maritime pilots decide to perform an overtaking manoeuvre?
9. RQ2: What are the cognitive processes of maritime pilots during an overtaking manoeuvre?
10. RQ4: What factors do pilots identify as influencing their decision-making process towards safe overtaking?

5.2 Choosing an approach

To further develop the results from previous study, a method was needed that can identify the mental models that pilots employ and the factors they consider when they decide to perform overtaking with safety. The required approach needs to be suitable for depicting such a complex and dynamic system, the factors that affect it and the cause-and-effect relationships. The approach should be also fitting for explaining the rationale of a pilot's decisions, for depicting the assessment of an overtaking situation and for uncovering the underlying reasons for the behaviour of the pilots on board. Having established a rapport and cooperation with the pilot station in Bremerhaven, it seemed like a logical step to look for an approach that could use the knowledge of available expert participants.

A Participatory modelling (PM) approach can engage the implicit and explicit knowledge of experts to create formalized and shared representations of their mental models. Based on graph theory, PM approaches use cognitive thinking and social networks to depict complex and dynamic systems (Yoon and Jetter 2016). The development of these models involves the participation of experts in one or more steps of the process.

For the current study, the criteria to choose a PM method were:

- the goal to describe a complicated dynamic system;
- the ease of use by participants;
- the use of visualization to explain and communicate the model properties and outputs to participants and other stakeholders;
- the ability to gather data from a limited number of experts in a short time due to the limitation of resources and
- the ability to quantify the qualitative data by creating a mathematical model that could be of further use in the future.

Bayesian networks (BNs) are an approach that can use and integrate qualitative data (e.g., the prior knowledge gained from experts or literature) and quantitative data (e.g., survey data). They are appropriate for the representation and automated reasoning by machine (Cheah et al. 2008). They are also well-suited for decision-making and risk analysis and have been applied in studies with maritime accidents (Adumene et al. 2022). However, creating Bayesian networks can be data-intensive, requiring more effort to specify the structure and parameters and to implement the algorithms of propagation of probabilities (van Vliet et al. 2010). The identification of probability percentages can be a difficult task for stakeholders. Also is not evident for a non-expert in this field how to construct a BN, and even more difficult how to combine different BN that describe the same system. Compared to BNs, FCMs can be simpler, more intuitive, more high-level, and more user-friendly. These features make it very appropriate for the acquisition of causal knowledge from pilots and for capturing effectively nonlinear relationships (Cheah et al. 2008).

The Analytic Hierarchy Process (AHP) was also considered at first for the purposes of the study. AHP is a three part process that includes identifying and organising decision objectives, criteria, constraints and alternatives into an hierarchy (Saaty 1981). It is a well-known structured method that uses pairwise comparisons with numerical values to quantify the relative importance of criteria and alternatives. AHP is more focused on quantitative comparison and is commonly used for decision-making involving multiple criteria and alternatives (Saaty 1988) and has been applied in many studies on decision making in the maritime domain (Lazakis and Ölçer 2016). However, it is more of a numerical analysis than visualization. In comparison, FCMs are more suited for capturing and visualizing complex, nonlinear relationships in systems with many interconnected factors. They can also model and understand complex systems and decision-making processes where qualitative relationships matter.

FCM appears to fit the criteria stated above better than BN and AHP approaches. Besides the BN and AHP approaches, most of the other methods are either too difficult for pilots who might not be trained in a participating in studies with such methods or take too much time and resources.

5.3 Methodological Approach and Procedure

The goal of the study was to explore the factors that impact sea pilots when they decide to overtake with safety in the specific scenario. The multistep FCM approach that is reported here was based on the process that is suggested by Olazabal et al. (2018) that have extended the approach by Özesmi and Özesmi (2004). Figure 43 shows a diagram that summarises these research activities and their outputs. The second part of this section describes in detail the procedure and the implementation of the validation.

5.3.1 The FCM multistep approach

Step 1: Problem Definition

As mentioned in 5.1 Introduction, the objective and scope definitions for the FCM case study were defined by the results from the ethnographic observations and the ACTA interviews. Defining the boundaries was a necessary process to avoid the development of a very complex model (Jetter and Kok 2014). The results and insights from the ACTA interviews (Cognitive Demands Table, Task Diagram) of the previous study indicated that preparation for overtaking is 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. Therefore, the design of the Knowledge Elicitation step was guided by these outputs.

Step 2: Knowledge Elicitation

A. **Identification of participants**

Selection of participants for the FCM building workshops followed the same pattern as the recruitment for the ACTA interviews. Using purposeful sampling, the corresponding sea pilot was asked to recommend expert mariners that had knowledge about overtaking in confined waters. The aim was to recruit at least five people that had not been involved in previous studies to minimize the bias and the subjectivity of the opinions.

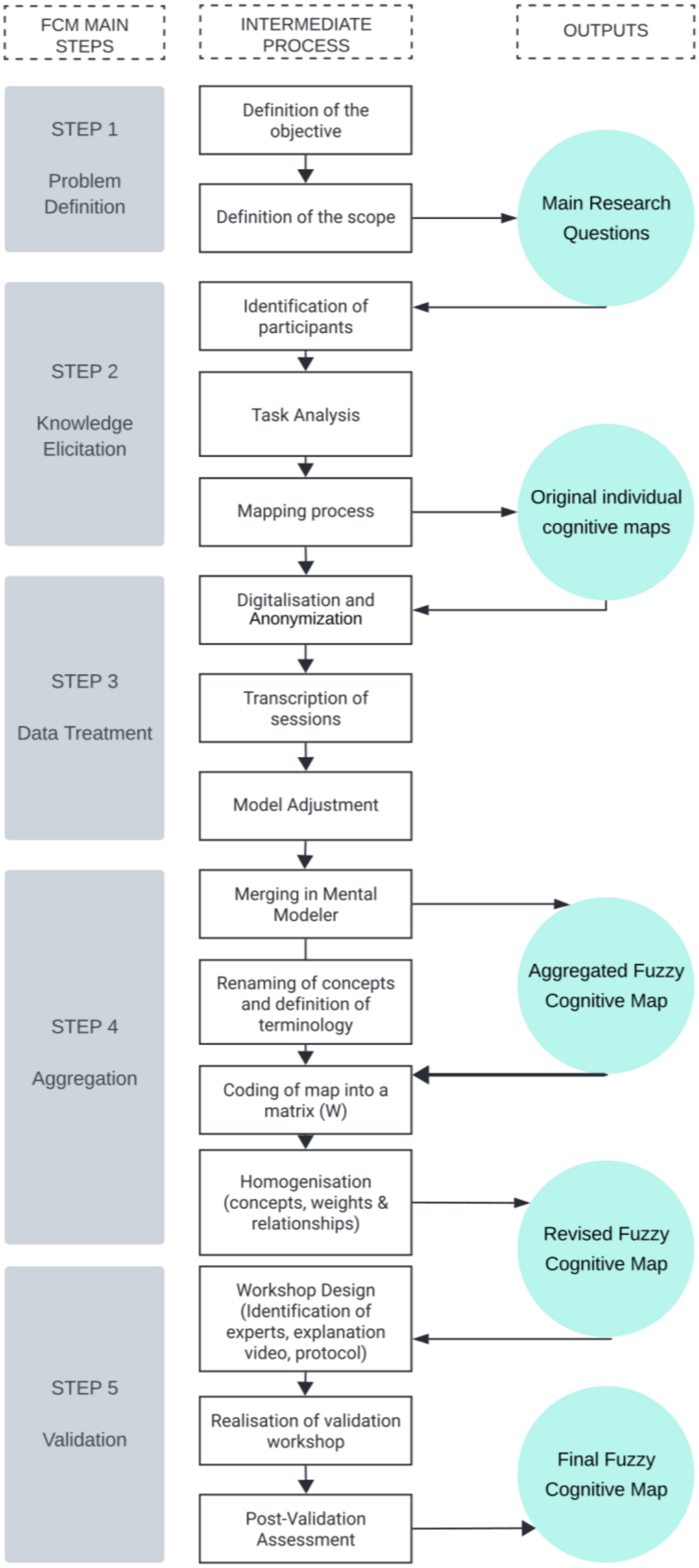


Figure 43 Detailed process and outputs of the Fuzzy Cognitive Map multistep approach.

B. Task Analysis

In this step, participants were prompted to give a walkthrough of the task using the ship models and markers on the printed nautical chart (same setting as seen in Figure 40). They were first asked to verify the Task Diagram from the ACTA interviews. Afterwards, the Simulation Interview (SI) from the ACTA toolkit was conducted in each workshop with the participants.

C. Mapping process

The mapping process was performed in two workshops that combined interviews and drawing activities with the participating expert sea pilots and consisted of the following phases:

- Presentation and explanation of the main questions to the participants:
- Instructions and examples to the participants to understand FCM semantics. As pointed out by Olazabal et al (2018), the examples were offered with variations at every step of the mapping process.
- Listing of the factors that are important for the main questions on paper using a pen or pencil.
- Drawing of factors in node format and connecting them with arrows to indicate the relationship.
- Determining the relationship as positive or negative.
- Assigning the influence of each relationship using a rating scale numbering from 1 to 5:

Scale of influence

(1) The strongest
(2) Very strong
(3) Somewhat strong
(4) Not very strong
(5) Not strong at all
Alternatively: I don't know

- Reviewing and discussing the maps.

Step 3: Data Treatment

The data treatment step included pre-processing, analysis and assessment activities that followed the collection of all individual maps and related data from Step 2:

- Anonymization of the collected data.
- Digitalisation of the original maps.
- Transcription of recorded sessions and analysis of the video recordings.
- Model adjustment.

Step 4: Aggregation of individual maps

Step 4 included the merging and homogenisation processes to create the final FCM.

A. Merging

The maps of the participants were merged though a visual and intuitive approach:

- Identification of common factors
- Placement of common factors in a new map
- Drawing of relationships between the common factors.
- Identification and addition of factors and relationships that were not present in all maps.
- Adjustment of the relationships
- Calculation of mean weights between factors to create the weight matrix (W)
- Iteration and refinement of the merged map.

B. Homogenization

- Assessment of the factors
- Evaluation of relationships, weights, and self-loops
- Update of the weight matrix (W)

Step 5: Validation

A. Design of the validation workshop

This step included all the actions to perform a qualitative validation to the FCM that was produced from the previous phases.

- Identification of experts
- Design of the workshop procedure and protocol

- Design of the material for the explanation of the goal to the participants and for the facilitation of the workshop

B. Realisation of the validation workshop

- Explanation of the modelling tool and process
- Assessment of all concepts, relationships and weights with the recruited experts

C. Post validation assessment

- Transcription of recorded sessions and analysis of the workshop recording
- Perform final revisions to concepts, relationships and weights based on total feedback
- Final update of the weight matrix (W)

5.3.2 Procedure

This section includes the procedure and the implementation of the validation workshop. Details on the procedures, protocols and related forms can be found in Appendices F (Guidelines for applying cognitive mapping methodology), G (Consent and Demographic forms for FCM workshops participants) and I (FCM validation workshop walkthrough).

Step 2: Knowledge Elicitation

A. Identification of participants

Six pilots were asked to participate in the mapping sessions in two groups of three. Eventually four participants were present in total, two in each workshop (WS). All four pilots were on active duty during the time of the mapping sessions. Their total seagoing experience ranged from 15 to 30 years (*M* = 20.75 years) on the date of the interviews. They had served as master mariners from 6 to 26 years (*M* = 10.8 years years). All four participants were male and active in the Pilots Association of Weser 2/Jade and their experience in pilotage ranged from 1 to 23 years (*M* = 9.3 years) on the date of the interviews. Table 5 contains the demographic and professional data that were collected from the participants on site.

	WS1/P1	WS1/P2	WS2/P3	WS2/P4	MEAN
YEARS ACTIVE	30	19	19	15	20.8
MASTER MARINER	26	6	11	8	12.8
PILOT	23	1	5	1,5	7.6
AGE	58	37	35	41	42.8

Table 5: The demographic and professional data of the participants in the FCM workshops. WS1 stands for Workshop 1, P1 stands for Participant 1 and so on.

B. Task Analysis

The SI technique, scenario, and materials were applied exactly as mentioned in the ACTA Simulation Interview section, except for the vessel direction being reversed (Table 6). Specifically, the container ship that would perform the overtaking in the scenario was outbound from Bremerhaven terminal and the vessel that was sailing from the opposite direction was inbound to the port. The reversed direction was changed on purpose, to examine a different perspective and gather data that would contribute to a more detailed overview of the overtaking manoeuvre in the region. The duration of the task analysis process was 55 minutes for WS1 and 40 min for WS2.

Scenario for the Simulation Interview in FCM workshops

You are the pilot on the container ship GUAYAQUIL that that has just left 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 inbound.

- Weather: T: 18-19°C, wind at 17Km/h (3Bft) SW, gusts at 33Km/h(5Bft), visibility 15km, cloudy
- High tide 3.37m at 10:52 AM, Low tide 0.5m at 5:25 PM
- Current: 3.3 knots on the surface and 2.5 knots at a depth of 2m below mean low water level
- Time is 12:00

Table 6: Scenario for the Simulation Interview in FCM workshops

C. Mapping process

First, the participants were presented with the main questions that guided the process:

- *What information elements and factors you take into consideration to assess the situation?*
- *How do you prioritize the conditions that must be present for the overtaking to occur?*

Following that, participants were shown an example of cognitive map of an infantry platoon leader using the METT-FC factors, as illustrated in Figure 44 (Jones et al. 2011). As stated in Olazabal et al (2018), the example was provided with variations at each stage of the mapping process to help clarify the concepts, links, and weights. SMEs were tasked to write the factors that they would consider for the scenario without contemplating which factor is crucial for each subtask of the TD that had previously been discussed.

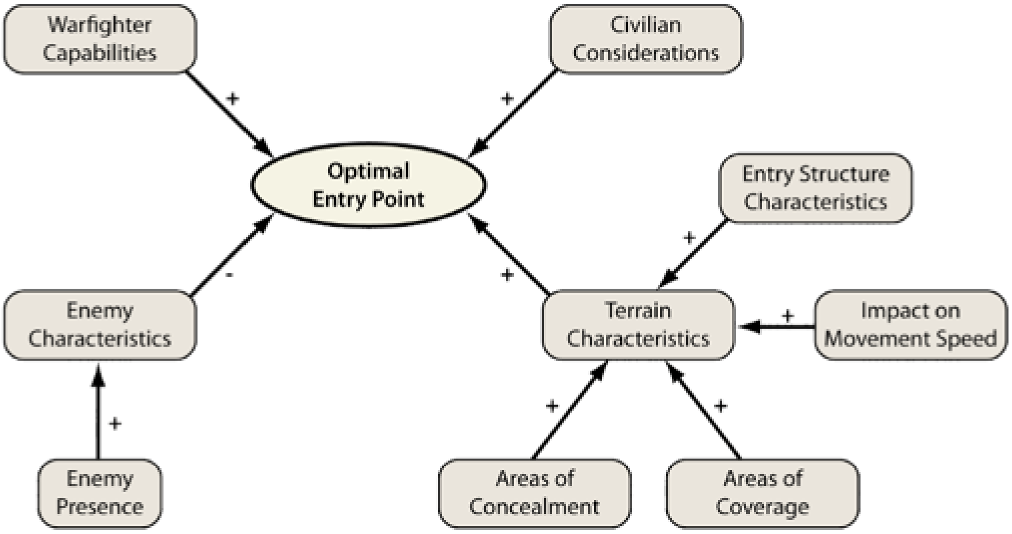


Figure 44 Abstracted version of the CM of METT-TC factors influencing Optimal Entry Point. Adapted by Jones et al. (2011).

Participants were instructed to examine all the factors they had written down and connect them with an arrow to illustrate the relationship in a new piece of paper using a pencil to allow for editing throughout the drawing phase. Not all the listed factors were included as nodes, and the participants added a few extra factors that were not included in their original lists. Participants were then asked to go over their maps' links and assign +/- to the arrows to indicate whether they had a positive or negative influence. Finally, they used the given scale of influence to determine the strength of each relationship between the factors on their map. The maps were discussed with the participants at the end of the procedure, which resulted in iterative adjustment of the nodes, relationships, and influence of the two maps. The mapping process lasted 90 minutes for WS1 and 80 minutes for WS2. Appendix H contains the scanned maps from this process.

Step 3: Data Treatment

For the purpose of maintaining the anonymity of their responses, each participant (P) was allocated an identification (ID) based on the workshop (WS) they attended. Participants in the first workshop were renamed P1/WS1 and P2/WS2, while those in the second session were given the IDs P3/WS2 and P4/WS2, as shown in Table 5.

The paper maps were scanned and then reproduced in the Mental Modeller online modelling programme. All sessions were video recorded and transcribed in Dovetail, with respect to the participants' IDs.

Model adjustment included a review of factors and their causal links, the treatment of redundant information, a review of conditional causalities (such as ship type as a factor), and the translation of any German phrases into English. Deviations from the FCM technique were also observed, such as writing an action as a node, e.g. "*other vessels supporting the manoeuvre by action*". These variations were occasionally handled by renaming variables, such as "*concerned pilots/captain "human factor*," which was called "*human factor*". The facilitator's notes, the maps and lists made by the modelling session participants, and the transcribed recorded sessions were all used as input in this step.

Step 4: Aggregation of individual maps

The merging process started with a review of each participant map to identify the elements that were shared by all four maps. These factors served as the starting points for the merged map. In Mental Modeler, a new file was produced in which the common map and causal relationships were drawn. This procedure was followed for each component and relationship identified when reviewing the maps. The technique also considered the data from the original maps and the pre-processing results from the previous stage. The weights were assigned a positive or negative value in the range [0,1], and the following transformation was used to convert the linguistic variable into precise numerical values:

Scale of influence

(1) The strongest = 1
(2) Very strong = 0.75
(3) Somewhat strong = 0.5
(4) Not very strong = 0.25
(5) Not strong at all = 0
Alternatively: I don't know

When the factors and relationships were completed, the nxn weight matrix (W) was produced, with n being the total number of nodes. The weights of the connections were equal to the average of the weights established by the pilots during the workshops for each of the existing relationships in the aggregated map. The credibility factor was one for all participants. The aggregated map's factors were reorganised for improved aesthetic appeal. Another iteration of relationship assessment and self-loop identification occurred during this procedure.

The homogenisation procedure comprised actions such as the deletion or substitution of factors that could not be expressed with a variable value (e.g. *expected manoeuvre*). It also entailed the process of integrating factors with comparable meanings to achieve common and consistent language across maps (for example, "*acceleration of vessel*" and "*speed of vessel*" were both renamed "*speed of vessel*"). There was also factor renaming (for example, "*Human Factor*" was renamed "*Human Factor (collaboration)*" to represent the level of teamwork between sailors). The previously detected self-loops were also evaluated, and the weight matrix (W) was ready for the final validation step.

The factor "*Visibility*" was also added, which was included in few of the lists created by participants at the start of the mapping sessions but was not included in their hand-drawn individual maps. The homogenisation was carried out with the assistance of an ergonomist who is well-versed in nautical navigation. A researcher with expertise in FCMs also reviewed the map after merging and homogenisation. The resulting FCM in this stage included 35 factors and 75 connections.

Step 5: Validation

The goal of the validation workshop was to evaluate the aggregated FCM with expert pilots and finalise its components. The participants for the validation workshops were chosen once more with the assistance of the corresponding on-site pilot. The pilot was asked to recommend expert mariners who were not employed at the same pilot station that provided the participants for the ACTA and FCM building sessions. This was done to increase the objectivity of the results by an independent assessment and to reduce bias with the participation of experts from various professional associations.

Table 7 includes demographic and professional information gathered from the pilots. The Typeform online survey tool was used to obtain demographic data and consent from the SMEs for the recording of the session, as well as to advise them about data processing, confidentiality, and GDPR issues. The experts were assigned with the codes VP1, VP2, and VP3 in order to erase any data that is personally identifiable.

	VP1	**VP2**	**VP3**	**MEAN**
SEA/PORT PILOT	sea	port	port	-
MASTER MARINER	25	4	4	11
PILOT	16	21	14	17
AGE	57	56	47	53.3

Table 7 The demographic and professional data of the participants in the FCM validation workshops.

Participants were given supplemental resources to prepare for the workshop, which included a video presentation, an explanation of the scenario and vessel specifics, a high-resolution image of the FCM, and a heatmap version of the weight (W) matrix. The video provided information on the overtaking scenario used in the FCM construction workshop, the fundamental concepts of the FCM, and the features of Mental Modeller. A guiding protocol was also developed to aid with conversation and moderation. The protocol included questions, comments, and remarks acquired during the preceding FCM construction steps (Appendix I).

On July 26, 2023, the workshop was held online via ZOOM with two facilitators and three pilots. After a brief introduction by the author, VP1 provided a quick overview of the major study goal and an explanation of the situation to VP2 and VP3. Following that, the main facilitator briefly discussed the validation results as well as the characteristics of the Mental Modeler tool (colour schemes, signs, and weights). The session continued with the analysis of 35 factors and 75 connections. The concept of "*Fatigue*" was added by the pilots during the validation session and there was discussion about the contribution of the *Manoeuvrability Characteristics* of the vessels. Participants also mentioned incidents and examples of challenges associated with manoeuvring in confined waters during the session.

The post validation assessment was undertaken primarily to determine whether there was anything amiss with the model that was produced during the workshop and to review the transcribed video for remarks that would be relevant to the research. The factors "*Manoeuvrability characteristics own vessel*" and "*Manoeuvrability characteristics VtO*" were the final addictions to the FCM at the end of the multistep process.

5.4 Results

The FCM model that was constructed and validated by the experts is depicted in Figure 45 and consists of 38 concepts and 82 connections. A blue direct relationship indicates a positive weight, and an orange link denotes a negative weight between the concepts.

Table 8 presents the list of the concepts contained in the final Safe Overtaking FCM, with a short description of them. The concepts are assigned an ID in the range C1, C2, …, C38 and some of them are highlighted with the similar shade as in Figure 45. These colours are associated with a preliminary grouping of factors for presentation purposes.

CONCEPT	**ID**	**DESCRIPTION**
SAFE OVERTAKING	C1	The output factor, associated with how safe the overtaking manoeuvre will be
Current Effect (Force, Direction)	C2	The degree of the influence of the current , a continuous, directed movement of water, defined by force or speed and direction
Wind Effect (Force, Direction)	C3	The intensity of the wind that acts on the vessel, which is defined by its force and direction
Sea State (Wave & Swell Height)	C4	The degree of the influence of the sea conditions, which refers to the height of the waves and the swell

Visibility	C5	The property of the atmosphere which determines the ability of an observer to see and identify prominent objects by day, or lights or lighted objects by night.
Tide Level	C6	High tide is when water advances to its furthest extent onto the shoreline. Low tide is when it recedes to its furthest extent
Fairway Width	C7	The fairway width is defined as a width of the cross-section of the river that corresponds to the fairway depth
Depth of Fairway	C8	The distance between the seabed/riverbed and the water surface
Speed Own Vessel	C9	The speed at which the vessel is cruising at any moment, measured in knots (kn)
Draft Own Vessel	C10	The vertical distance from the moulded base line amidships to the actual waterline
Size Own Vessel	C11	The dimensions of a vessel that determine its size (beam overall, length overall) expect draft
Manoeuvring characteristics own vessel	C12	The quality of the inherent turning, yaw-checking, course-keeping and stopping abilities of a vessel
Manoeuvrability Own Vessel	C13	A ship's manoeuvrability determines its capability to change course under certain navigational conditions
Speed Vessel to Overtake	C14	The speed at which the vessel to be overtaken is cruising at any moment, measured in knots (kn)
Draft Vessel to Overtake	C15	The vertical distance from the moulded base line amidships to the actual waterline
Vessel Size Vessel to Overtake	C16	The dimensions of a vessel that determine its size (beam overall, length overall) expect draft
Manoeuvring characteristics VtO	C17	The quality of the inherent turning, yaw-checking, course-keeping and stopping abilities of a vessel
Manoeuvrability Vessel to Overtake	C18	A ship's manoeuvrability determines its capability to change course under certain navigational conditions
Optimal Position of Vessel to Overtake in Fairway	C19	In a narrow channel overtaking should normally take place on the port side[1] as the vessel being overtaken (VtO) should be as far as practicable on the starboard side of the channel, which indicates the optimal position
Speed of Other Vessels	C20	The speed of the vessel from the opposite direction that might affect the overtaking maneuver
Manoeuvrability of Other Vessels	C21	A ship's manoeuvrability determines its capability to change course under certain navigational conditions
Vessel Size Other Traffic	C22	The dimensions of a vessel that determine its size (beam overall, length overall)

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[1] When looking forward, toward the bow of a ship, port and starboard refer to the left and right sides, respectively (NOOA, 2023)

Speed Difference	C23	The difference between the speed of the overtaking vessel and speed of the vessel being overtaken
Effective Area of Overtaking	C24	The segment of the fairway where the overtaking will occur
Complexity of Traffic Situation	C25	The traffic congestion state of the fairway that increases the navigation difficulty
Ship to Ship Interaction	C26	The hydrodynamic interaction that occurs when the when the typical flow of water around the hull of the own vessel is constrained by the influence of the VtO
Time /Space Required	C27	The duration and area that are needed to perform overtaking with safety
Availability of Backup Power	C28	Refers to the capacity of the equipment to allow gradual increase on power and speed, indicated by the temperature of the engine and the available volume of water for the propeller, etc
Under Keel Clearance	C29	The difference between the depth of the water and the draft of the vessel at a point in time.
Quantity of Vessels in Fairway	C30	The amount of the vessels of any size that are in the fairway
Time Pressure	C31	A vessel might have an Estimated Time Arrival (ETA) to a port location
Regulations & VTS Restrictions	C32	Traffic regulations and management by the the nearshore vessel traffic management system that ensure the safety of the traffic in the fairway
Human Performance (Collaboration)	C33	The effectiveness of the cooperation between mariners on board and inshore in relation to navigation
Own Experience	C34	The professional experience of the pilot on board the own vessel
Professionalism of The Master Own Vessel	C35	Associated with how excellent the master's professional maritime skills are
Professionalism of The Other Pilot	C36	Associated with how excellent the professional maritime skills and experience of the pilot of the VtO are
Communication With Other Vessel(s)	C37	The effectiveness of communication between vessels that are involved in the overtaking situation
Fatigue	C38	A state of weariness that can significantly increase the risk of accidents, with physical, cognitive, and behavioural signs.

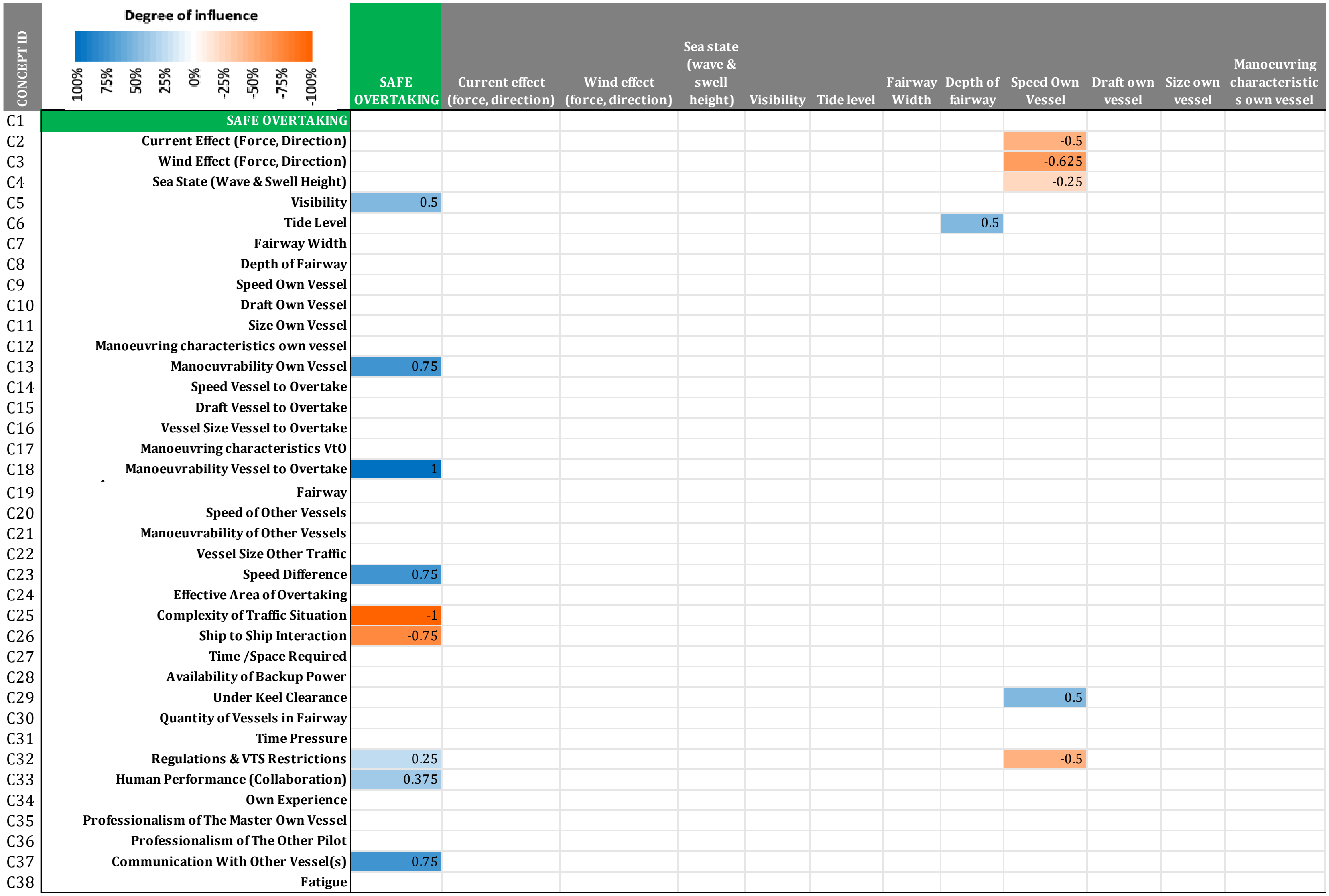
Table 8 List of concepts of the FCM

Concepts C1, C2, C3, C4, C5, C6, C7 and C8 represent factors that are related to environmental aspects. Concepts C9, C10, C11, C12, C13 and C29 are factors related to the own ship status category, which refers to the vessel that the pilot is supposed to be on board for the scenario. Concepts C14, C5, C16, C17, C18 andC19 are factors related to the VtO group, which is the coaster vessel in the scenario. C20, C21 and C22 are concepts relevant to the cargo vessel that is approaching from the opposite direction and other possible traffic. C33, C34, C35, C36 and C38 are concepts related to human factors. The rest of the concepts describe factors linked to calculations and comprehension activities that pilots perform (C23 to C27), traffic aspects (C30, C32), and communication and operational aspects. Lastly, C1 stands for Safe Overtaking that is the output concept.

The adjacency matrix of the FCM was created accordingly, including the causal relationships between the concepts and their weight (Table 9). Each number of this weight matrix represents the causal relationship between the concepts that are seen in the corresponding row and column of this matrix. Table 10 displays a heat map of the adjacency matrix, where only the cells that contain weights other than zero are indicatively coloured.

0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28	C29	C30	C31	C32	C33	C34	C35	C36	C37	C38
C1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C2	0	0	0	0	0	0	0	0	-0.5	0	0	0	-0.25	-0.5	0	0	0	-0.6	0	-0.25	0	0	-0.5	-0.625	0	-0.5	0	0	0	0	0	0	0	0	0	0	0	0
C3	0	0	0	0	0	0	0	0	-0.625	0	0	0	-0.625	-0.3	0	0	0	-0.62	0	-0.62	-0.62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C4	0	0	0	0	0	0	0	0	-0.25	0	0	0	-0.1	-0.5	0	0	0	-0.5	0	-0.25	-0.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C5	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C6	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C7	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0.5	0	0	0.5	0	0	0.75	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0
C8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75	0	-0.5	0	0	0.75	0	0	0	0	0	0	0	0	0
C9	0	0	0	0	0	0	0	0	0	0	0	0	0.75	0	0	0	0	0	0	0	0	0	0.75	0.25	0.5	0	0	0	-0.5	0	0	0	0	0	0	0	0	0
C10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	-0.7	0	0	0	0	0	0	0	0	0
C11	0	0	0	0	0	0	0	0	0	0	0	0	-0.5	0	0	0	0	0	0	0	0	0	0	0	-0.5	0.5	0	0	0	0	0	0	0	0	0	0	0	0
C12	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C13	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75	0	0	0	0	-0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.5	0	0	0	0	0	-1	0	-0.3	0	0	0	0	0	0	0	0	0	0	0	0
C16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.5	0	0	0	0	0	0	-0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
C17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C18	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	-0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
C22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.5	0	0	0	-0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
C23	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	-0.75	0	0	0	0	0	0	0	0	0	0	0
C24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0
C25	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.625	-0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C26	-0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.75	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
C28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C29	0	0	0	0	0	0	0	0	0.5	0	0	0	0.75	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	0	0
C31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.25	0	0	0	0	0
C32	0.25	0	0	0	0	0	0	0	-0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C33	0.375	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75	0	0	0	0	0
C35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0	0	0	0
C36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0	0
C37	0.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.25	0	0	0	0	0
C38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0.5	0	0	0	0	0

Table 9 The Adjacency matrix



CONCEPT ID		SAFE OVERTAKING	Current effect (force, direction)	Wind effect (force, direction)	Sea state (wave & swell height)	Visibility	Tide level	Fairway Width	Depth of fairway	Speed Own Vessel	Draft own vessel	Size own vessel	Manoeuvring characteristics own vessel
C1	SAFE OVERTAKING												
C2	Current Effect (Force, Direction)									-0.5			
C3	Wind Effect (Force, Direction)									-0.625			
C4	Sea State (Wave & Swell Height)									-0.25			
C5	Visibility	0.5											
C6	Tide Level								0.5				
C7	Fairway Width												
C8	Depth of Fairway												
C9	Speed Own Vessel												
C10	Draft Own Vessel												
C11	Size Own Vessel												
C12	Manoeuvring characteristics own vessel												
C13	Manoeuvrability Own Vessel	0.75											
C14	Speed Vessel to Overtake												
C15	Draft Vessel to Overtake												
C16	Vessel Size Vessel to Overtake												
C17	Manoeuvring characteristics VtO												
C18	Manoeuvrability Vessel to Overtake	1											
C19	Fairway												
C20	Speed of Other Vessels												
C21	Manoeuvrability of Other Vessels												
C22	Vessel Size Other Traffic												
C23	Speed Difference	0.75											
C24	Effective Area of Overtaking												
C25	Complexity of Traffic Situation	-1											
C26	Ship to Ship Interaction	-0.75											
C27	Time /Space Required												
C28	Availability of Backup Power												
C29	Under Keel Clearance									0.5			
C30	Quantity of Vessels in Fairway												
C31	Time Pressure												
C32	Regulations & VTS Restrictions	0.25								-0.5			
C33	Human Performance (Collaboration)	0.375											
C34	Own Experience												
C35	Professionalism of The Master Own Vessel												
C36	Professionalism of The Other Pilot												
C37	Communication With Other Vessel(s)	0.75											
C38	Fatigue												

Table 10 A heat-map that shows the weights of each relationship between concepts with colour scale.

CONCEPT ID	Manoeuvrability own vessel	Speed VtO	Draft VtO	Vessel size VTO	Manoeuvring characteristics VtO	Manoeuvrability VtO	Optimal Position of VtO in fairway	Speed of other vessels	Manoeuvrability other vessels	Vessel Size other traffic	Speed Difference	Effective Area of overtaking	Complexity of Traffic Situation	Ship to Ship Interaction
C1														
C2	-0.25	-0.5				-0.6		-0.25			-0.5	-0.625		-0.5
C3	-0.625	-0.3				-0.62		-0.62	-0.62					
C4	-0.1	-0.5				-0.5		-0.25	-0.1					
C5														
C6														
C7	0.5					0.5			0.5			0.75		0.5
C8												0.75		-0.5
C9	0.75										0.75	0.25	0.5	
C10												-1		
C11	-0.5												-0.5	0.5
C12	0.5													
C13														
C14						0.75					-0.75			
C15						-0.5						-1		-0.3
C16						-0.5							-0.5	
C17						0.5								
C18														
C19												0.75		
C20									0.5		-0.75			
C21													-0.5	
C22									-0.5				-0.5	
C23														-1
C24													-1	
C25											-0.625	-0.25		
C26														
C27												-0.75	0.5	
C28											0.25			
C29	0.75											0.5		
C30													-1	
C31														
C32														
C33														
C34														
C35														
C36														
C37														
C38														

Table 10 (cont) A heat-map that shows the weights of each relationship between concepts with colour scale

CONCEPT ID	Time /space required	Availability of backup power	Under Keel Clearance	Quantity of vessels in fairway	Time Pressure	Regulations & VTS Restrictions	Human Performance (Collaboration)	Own experience	Professionalism of the master own vessel	Professionalism of the other pilot	Communication with other vessel(s)	Fatigue
C1												
C2												
C3												
C4												
C5												
C6												
C7												
C8			0.75									
C9			-0.5									
C10			-0.7									
C11												
C12												
C13												
C14												
C15												
C16												
C17												
C18												
C19												
C20												
C21												
C22												
C23	-0.75											
C24												
C25												
C26												
C27												
C28												
C29												
C30												
C31							-0.25					
C32												
C33												
C34							0.75					
C35							0.25					
C36							0.5					
C37							0.25					
C38							-0.5					

Table 10 (cont) A heat-map that shows the weights of each relationship between concepts with colour scale

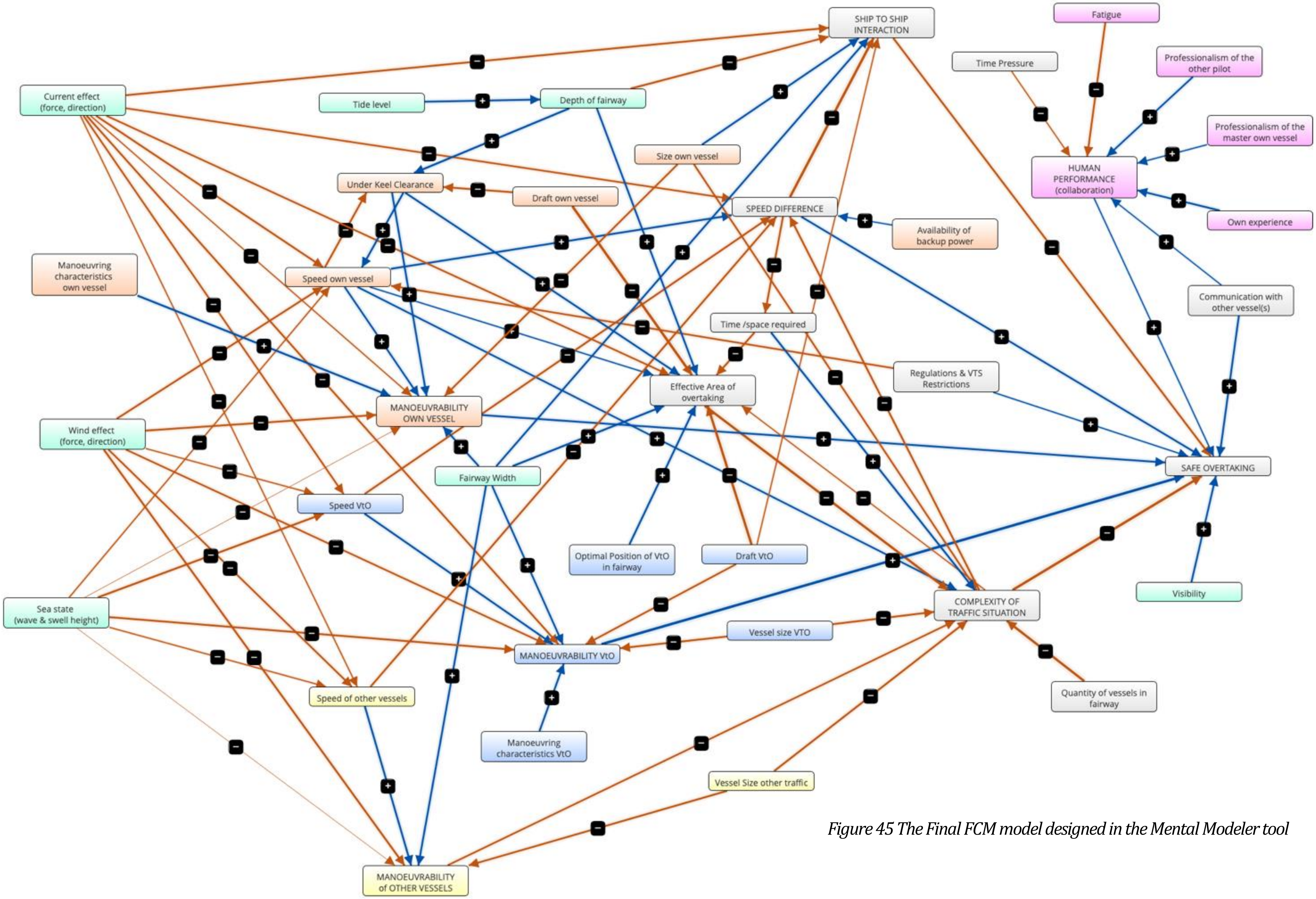


Figure 45 The Final FCM model designed in the Mental Modeler tool

5.5 Structural Analysis

The Mental Modeler tool was used to calculate the network structural analysis for the FCM (Özesmi and Özesmi, 2004). Structural analysis aims to describe and analyse the overall graphical structure of the FCM and to identify concepts of particular interest in the map (Blacketer et al. 2021). These measures are the number of (1) component connections, (2) transmitter components, (3) receiver components, (4) ordinary components, as well as (5) density, (6) connections per component, and (7) complexity score of the model (See Table 11). Mental Modeler also provided component-level metrics, including (a) centrality, (b) indegree, (c) outdegree, and (d) type for each component (see Table 12).

Metric	**Value**
Total Components	38
Total Connections	82
Density	0.058321
Connections per Component	2.157895
Number of Transmitter Components	23
Number of Receiver Components	1
Number of Ordinary Components	14
Complexity Score	0.043478

Table 11 Metrics from the structural analysis

The number of transmitter, receiving, or ordinary variables and the complexity scores may indicate whether the FCM is viewed as largely comprised of transmitter components or whether the outcomes of transmitting forces are considered (i.e. that some components are only influenced). In this FCM, 23 out of the 38 concepts are transmitter concepts and the ordinary concepts are 14. As the sole receiver concept of the system, *Safe Overtaking* - C1 can be considered as the main output indicator while comparing the impact of different scenarios on the system that the FCM depicts (Table 11).

CONCEPT	CENTRALITY	INDEGREE	OUTDEGREE	TYPE
Effective Area of Overtaking	7.625	6.625	1	ordinary

Complexity Of Traffic Situation	6.875	5	1.875	ordinary
Speed Difference	6.125	3.625	2.5	ordinary
Safe Overtaking	6.125	6.125	0	receiver
Manoeuvrability VtO	5.47	4.47	1	ordinary
Speed Own Vessel	5.125	2.375	2.75	ordinary
Manoeuvrability Own Vessel	4.725	3.975	0.75	ordinary
Ship To Ship Interaction	4.05	3.3	0.75	ordinary
Current Effect (Force, Direction)*	3.725	0	3.725	transmitter
Under Keel Clearance	3.7	1.95	1.75	ordinary
Wind Effect (Force, Direction)*	3.41	0	3.41	transmitter
Human Performance (Collaboration)	2.875	2.5	0.375	ordinary
Speed VtO	2.8	1.3	1.5	ordinary
Fairway Width*	2.75	0	2.75	transmitter
Manoeuvrability Of Other Vessels	2.72	2.22	0.5	ordinary
Depth Of Fairway	2.5	0.5	2	ordinary
Speed Of Other Vessels	2.37	1.12	1.25	ordinary
Time /Space Required	2	0.75	1.25	ordinary
Draft VtO*	1.8	0	1.8	transmitter
Draft Own Vessel*	1.7	0	1.7	transmitter
Sea State (Wave & Swell Height) *	1.7	0	1.7	transmitter
Size Own Vessel*	1.5	0	1.5	transmitter
Communication With Other Vessel(s)*	1	0	1	transmitter
Vessel Size Other Traffic*	1	0	1	transmitter
Vessel Size VTO*	1	0	1	transmitter
Quantity Of Vessels in Fairway*	1	0	1	transmitter
Regulations & VTS Restrictions*	0.75	0	0.75	transmitter
Optimal Position of VtO in Fairway*	0.75	0	0.75	transmitter
Own Experience*	0.75	0	0.75	transmitter
Professionalism Of the Other Pilot*	0.5	0	0.5	transmitter
Tide Level*	0.5	0	0.5	transmitter
Visibility*	0.5	0	0.5	transmitter
Fatigue*	0.5	0	0.5	transmitter
Manoeuvring Characteristics Own Vessel*	0.5	0	0.5	transmitter
Manoeuvring Characteristics VtO*	0.5	0	0.5	transmitter
Time Pressure*	0.25	0	0.25	transmitter
Professionalism of the Master Own Vessel*	0.25	0	0.25	transmitter
Availability Of Backup Power*	0.25	0	0.25	transmitter

Table 12 Centrality, Indegree and Outdegree indices along with concept type created by Mental Modeler. The data are sorted by highest degree of centrality. The transmitter concepts are indicated by an asterisk (*) near their name.

In Table 12 the concepts are sorted by their centrality, which reflects the complexity of the FCM as it is and reveals the degree of influence of each concept. In descending order, the concepts with a degree of centrality larger than 2 are:

- *Effective Area of Overtaking* (C24)
- *Complexity of Traffic Situation* (C25)
- *Speed Difference* (C23)
- *Safe Overtaking* (C1)
- *Manoeuvrability* of *VtO* (C18)
- *Speed Own Vessel* (C9)
- *Manoeuvrability Own Vessel* (C13)
- *Ship to Ship Interaction* (C26)
- *Current Effect* (C2)
- *Under Keel Clearance* (C29)
- *Human Performance (Collaboration)* (C33)
- *Speed VtO* (C14)
- *Fairway Width* (C7)
- *Manoeuvrability Of Other Vessels* (C21)
- *Depth Of Fairway* (C8)
- *Speed Of Other Vessels* (C20)
- *Time /Space Required* (C27)

These concepts are also indicated in bold in Table 12. On the other hand, the concepts *Time Pressure* (C31), *Professionalism of the master own vessel* (C35) and *Availability of backup power* (C28) have the lowest centrality score.

As seen in Figure 46 and the structural analysis indices (Table 12), several factors influence the output concept *Safe Overtaking* (C1). *Manoeuvrability VtO* [+1] has the strongest positive influence on C1 and its centrality value is >5. *Speed Difference* [+0.75], *Manoeuvrability Own Vessel* [+0.75], *Communication with other vessel(s)* [+0.75] have also a very strong positive impact on C1 and *Human Performance (collaboration)* [+0.375] has a moderately positive effect on C1. The factors *Regulations & VTS*

Restrictions [+0.25] and *Visibility* [+0.5] also influence positively C1 but have a lower centrality score compared to the other factors but. On the contrary, the factors *Complexity of Traffic Situation* [-1] and *Ship to Ship Interaction* [-0.75] have respectively the strongest and a very strong negative influence on C1. *Complexity of Traffic Situation* is the factor with the second highest centrality score (Figure) and the third highest indegree value in the FCM. According to these metrics and the scores, *Complexity of Traffic Situation* (Figure 52*)* and *Manoeuvrability VtO* (Figure 50) are perceived as the most relevant factors to Safe Overtaking.

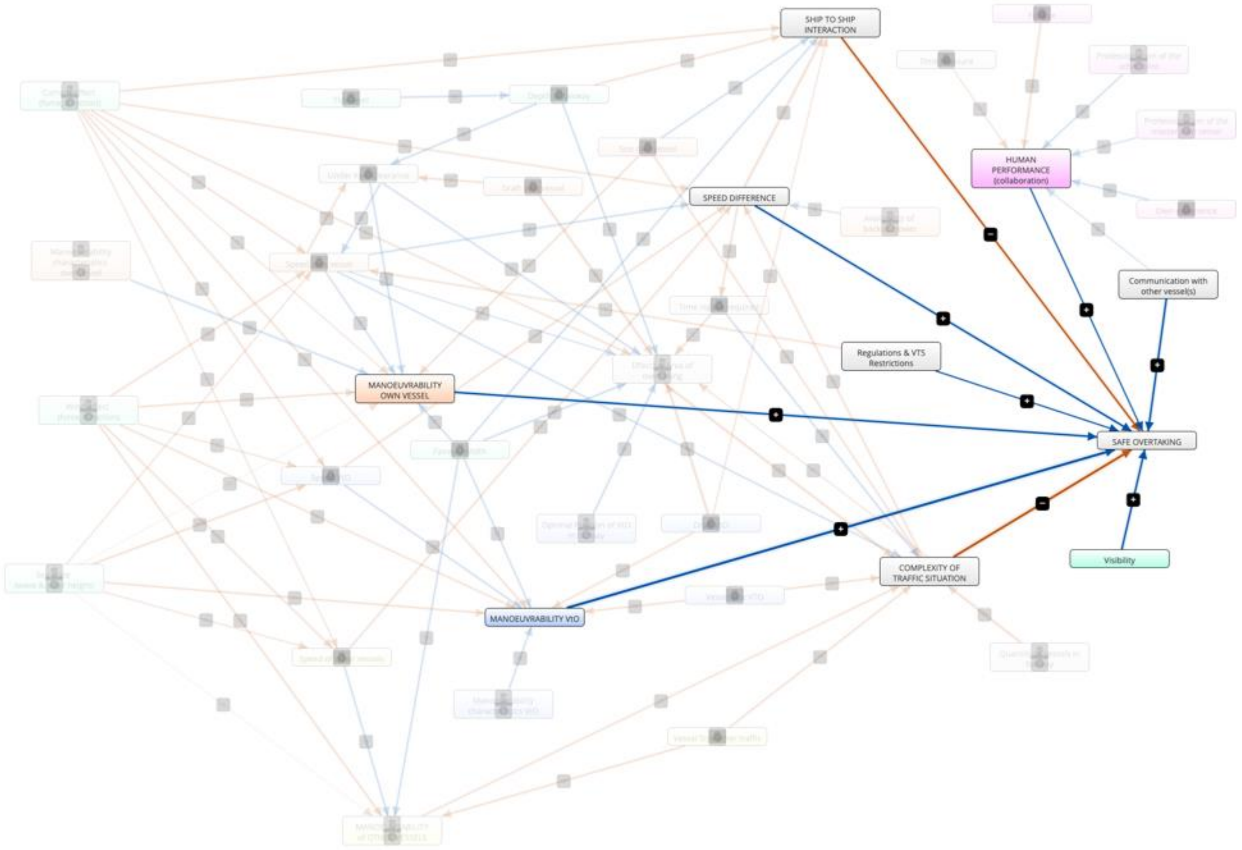


Figure 46 An isolated view of the factors that have a direct influence on the concept of Safe Overtaking (C1). Blue lines represent positive influnce, orange lines represent negative influence.

The higher degree of centrality in some concepts demonstrates their importance in participants' perception compared to the rest of the concepts. This ascertains that not all environmental or vessel status related concepts are necessarily central, thus they are not the most important as standalone concepts in the mental model of the pilots in estimating the safety of the manoeuvre. Based on its centrality score, the concept *Effective Area of Overtaking* (C24) gives and receives the greatest direct influence on all other concepts in the map (Figure 47), whereas *Availability of Backup Power* (C28), *Time Pressure* (C31) and *Professionalism of The Master Own Vessel* (C35) give and receive the least. The concepts of *Speed Difference* (C23) and *Speed Own Vessel* (C9) have a high value of the three major indices values (centrality, indegree and outdegree). These metrics show that the concepts of *Speed Difference* (Figure 49*)* and *Speed Own Vessel* (Figure 48) have a considerable impact in the FCM as both a transmitter (influential) and receiver (dependent) factor. The concepts with an outdegree value > 1 are indicated by the green coloured table cell and the concepts with an indegree value >1 are signified by the purple coloured cell in the respective columns for Indegree and Outdegree in Table 12.

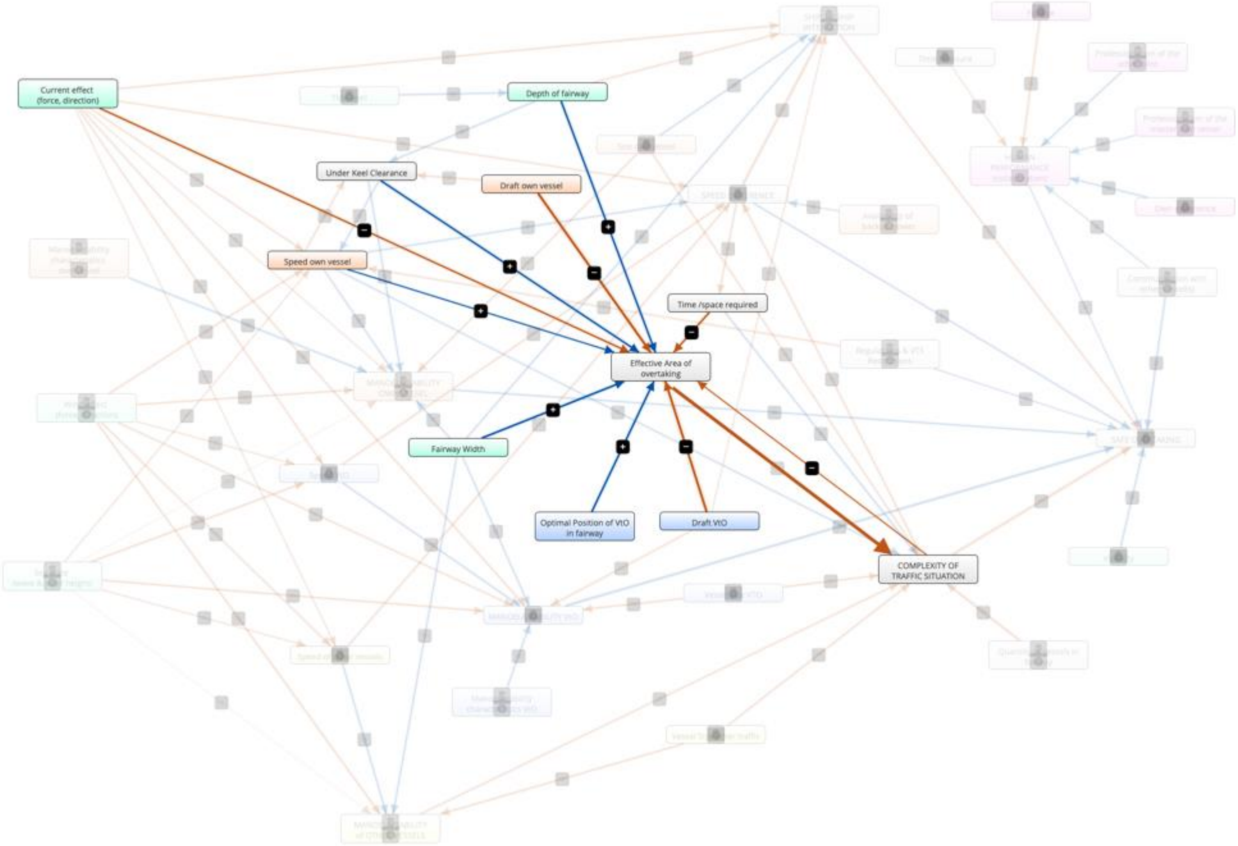


Figure 47 The concept Effective Area of Overtaking (C24) has the highest centrality score in the FCM. It indirectly affects Safe Overtaking by having the strongest negative influence on the factor of Complexity of Traffic Situation (C25) that influences directly Safe Overtaking.

The type of component may indicate how the participants think about the factor during the modeling workshops. For instance, if someone views a component as a transmitter concept, it is seen as a forcing function, which cannot be controlled by any other concepts (Özesmi and Özesmi 2004). The transmitter concepts have non-zero *outdegree* and zero *indegree* and they control the model but are not affected by any changes in it. Transmitter concepts indicate the variables on which the outcome of an intervention depends to affect the concept of safe overtaking. While conducting scenario analysis, they can be used to discover how the outcome of the interaction of concepts differs under various influences. The environmental factors are all transmitter components. Factors *Current effect (*C2*),* Wind effect (C3), Fairway Width (C7) are also the transmitter concepts in the whole map that have the highest outdegree value, and also the highest centrality amongst transmitter concepts, while *Time Pressure* (C31), *Professionalism of the master own vessel* (C35) and *Availability of backup power* (C28) have the lowest outdegree value.

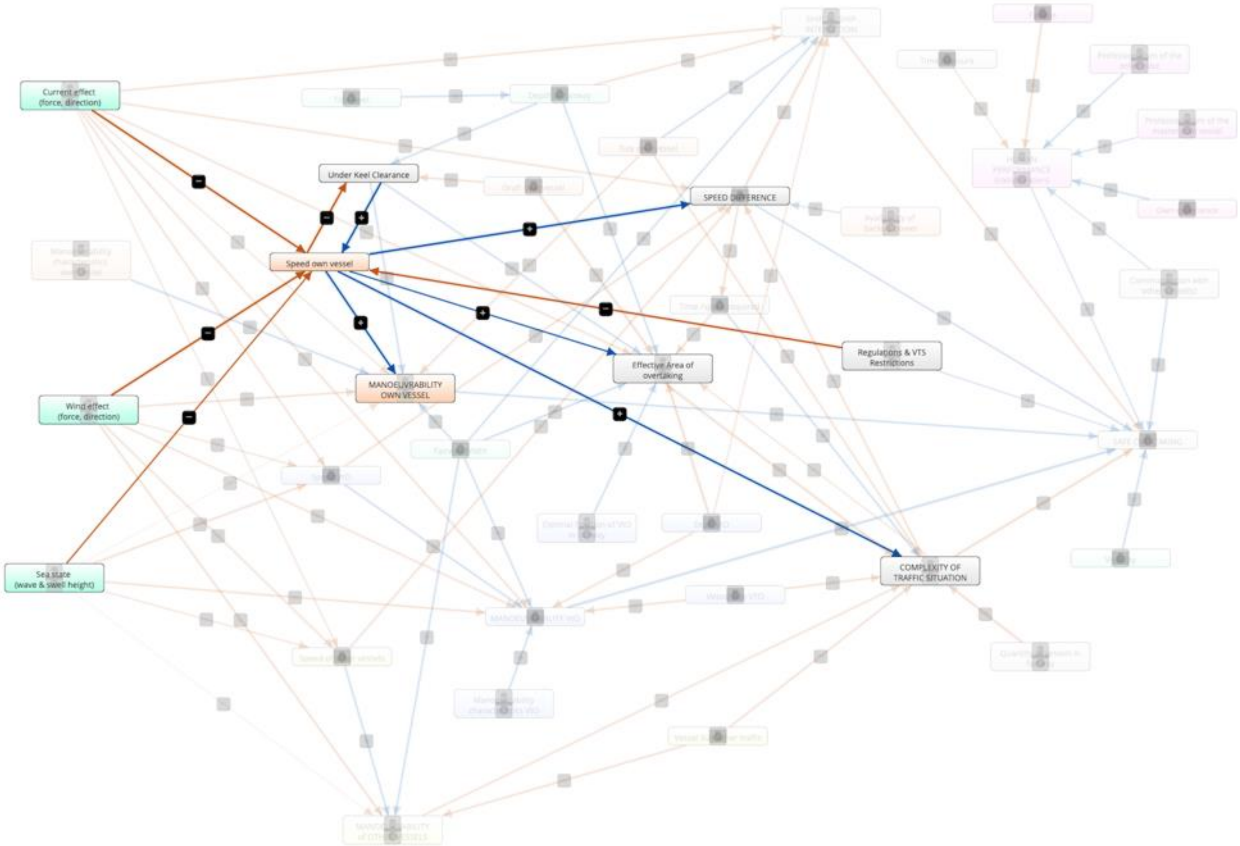


Figure 48 An isolated view of the relationships between the factor Speed own vessel (C9) and other factors in the FCM.

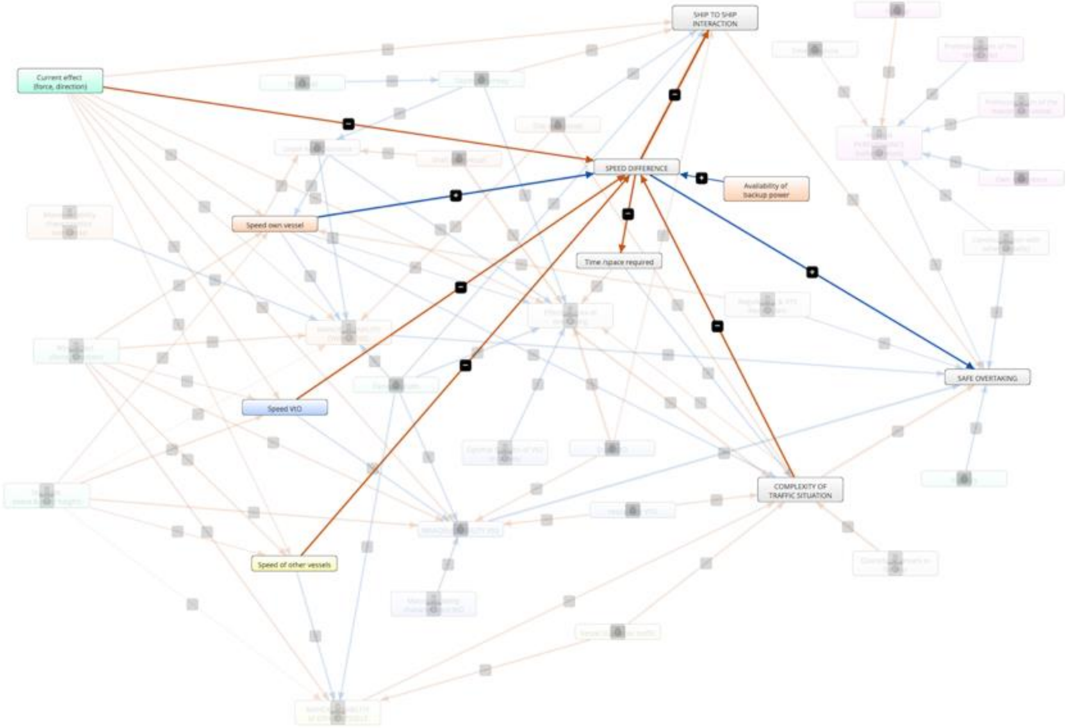


Figure 49 An isolated view of the relationships between the factor Speed Difference (C23) and other factors in the FCM.

From the perspective of the structural analysis, the concept *Effective Area of Overtaking* (C24) is the most relevant factor in relation to Safe Overtaking, even if there is no direct link between them (Figure 47). The *Effective Area of Overtaking* is impacted by ten other factors and affects the *Complexity of the Traffic situation (C25).* The cause-and-effect relationships between the factors show that the concept of Safe Overtaking (C1) is improved when the value of factors *Manoeuvrability VtO*, *Speed Difference*, *Manoeuvrability Own Vessel*, *Communication with other vessel(s)*, *Human Performance, Regulations & VTS Restrictions* and *Visibility* increases. However, when the values of *Complexity of Traffic Situation* and *Ship to Ship Interaction* increase, the effect on C1 is negative.

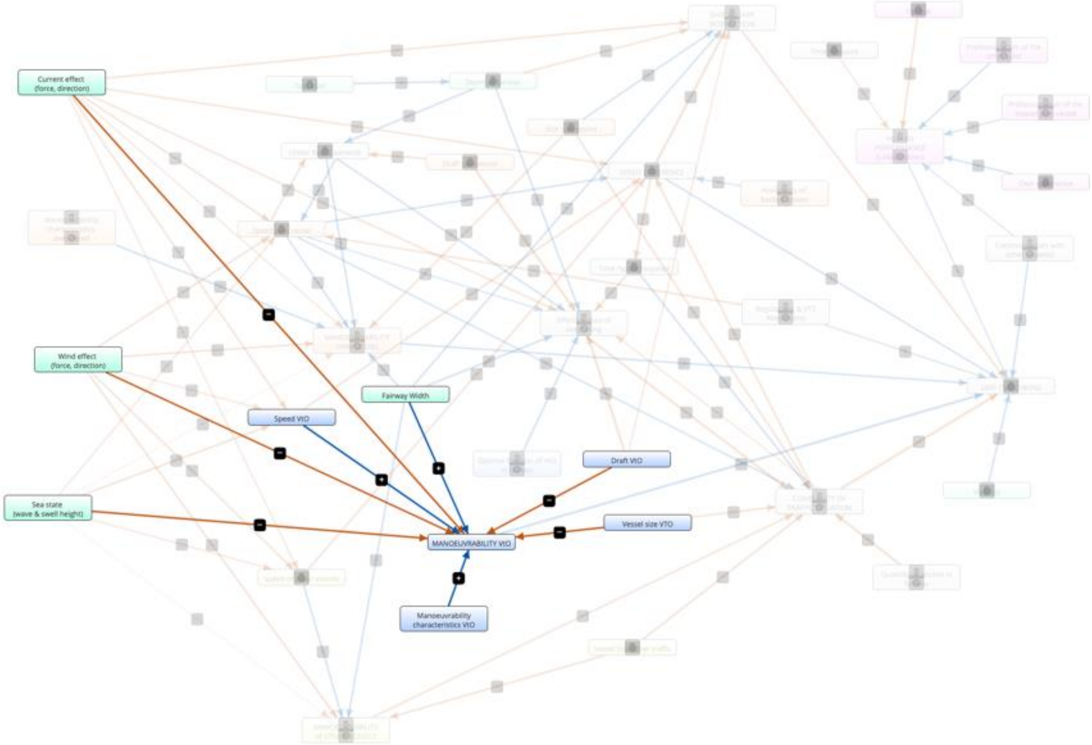


Figure 50 An isolated view of the factors affecting Maneuverability VtO (C18) in the FCM

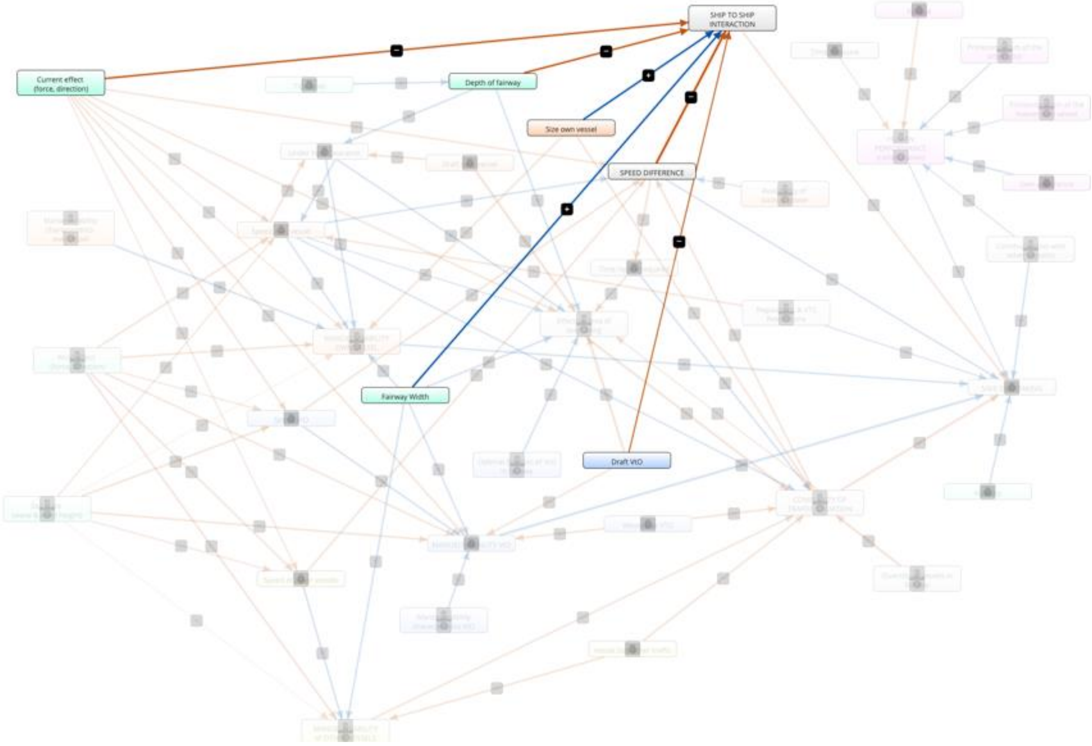


Figure 51 An isolated view of the factors affecting Ship to Ship Interaction (C26) in the FCM

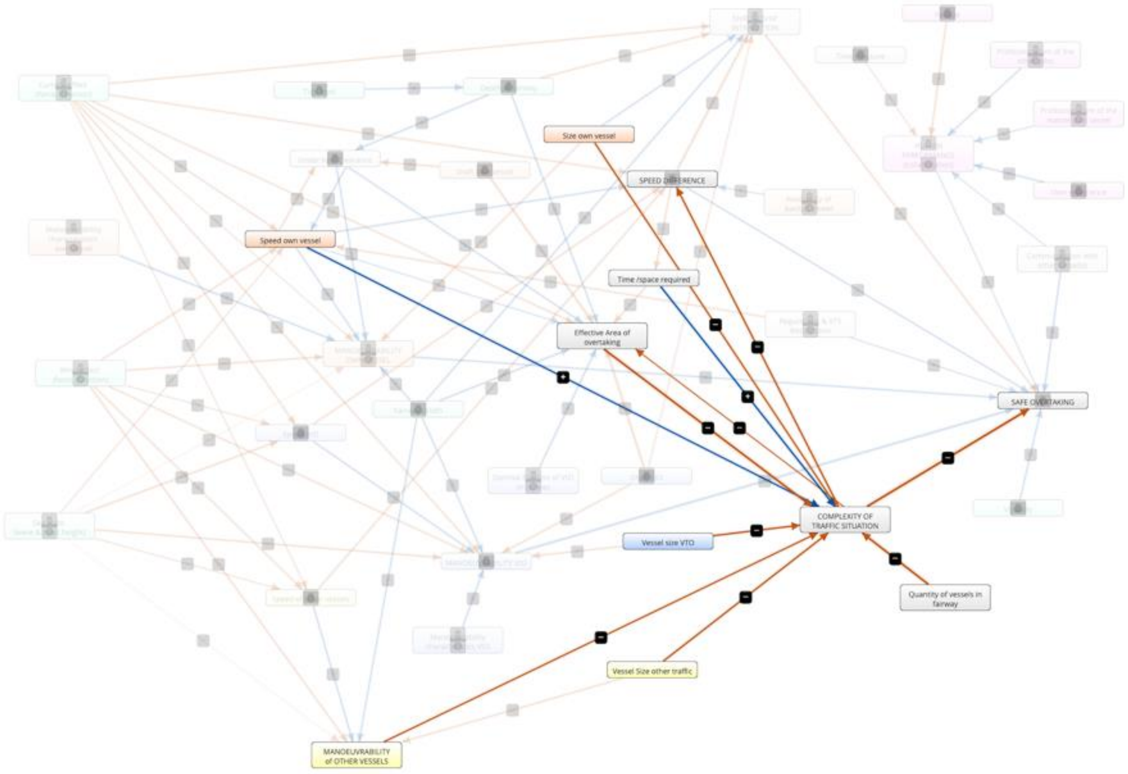


Figure 52 An isolated view of the relationships between the factor Complexity of Traffic Situation (C25) and other factors in the FCM

5.6 Discussion of Results

The results of this study provided insights into which factors most strongly influence decision making for safe overtaking and explored the interrelationships and co-dependencies between them. To achieve this, Fuzzy Cognitive Mapping (FCM) techniques were employed to derive and model the factors and their connections with the participation of four expert sea pilots from the Bremerhaven port. The product of this process was then evaluated and validated in a workshop by three different pilots. The final FCM consists of 38 factors, namely environmental, ship related, traffic, human factors, and organizational factors, and their interdependencies that are defined by 82 relationships. Finally, a structural analysis was done to examine the direct and indirect impacts of the concepts and to provide insights into components of particular significance in the map.

The focus of the study was to demonstrate how FCMs may render individual sea pilots' implicit knowledge of safe overtaking discernible to themselves and each other. The participating mariners were each able to visualize and provide key components of their perspective of a complex situation such as overtaking another vessel on their own. A major advantage from the study is the use of FCM which can allow the consolidated depiction of the mental models of all the participating experts. The graphical format of the FCM and the use of the Mental Modeler enabled the pilots of the validation workshop to grasp quickly not only the content of the FCM that was to be evaluated, but also the methodological aspects themselves, as the coloured elements and connections can indicate the connections and signs of the weights.

5.6.1 FCM as a representation of SA

The factors that have been identified via the FCM technique can be used to represent how pilots build and maintain SA during the overtaking manoeuvre, since the depicted cognitive map can replicate human cognition. FCMs can enable the representation of links between important information elements and factors that support the development of higher cognitive levels required for effective decision-making. In their SA-FCM model, Jones et al. (2011) have suggested how the FCM can represent and demonstrate the comprehension (Level 2 SA) and projection (Level 3 SA) of how the data impacts current and future situations.

The produced FCM model may be used to represent the three levels of SA. The decision to overtake is situated in factors that are related to the SA levels 2 and 3, meaning comprehension of cues and projection of the future situation. Figure 53 suggests a graphical organisation in a manner that associates the factors with the three levels of SA, based on the structural analysis results:

- The 23 transmitter concepts– level 1 SA
- The 14 ordinary concepts – level 2 SA
- The 1 receiver concept (Safe Overtaking) – level 3 SA

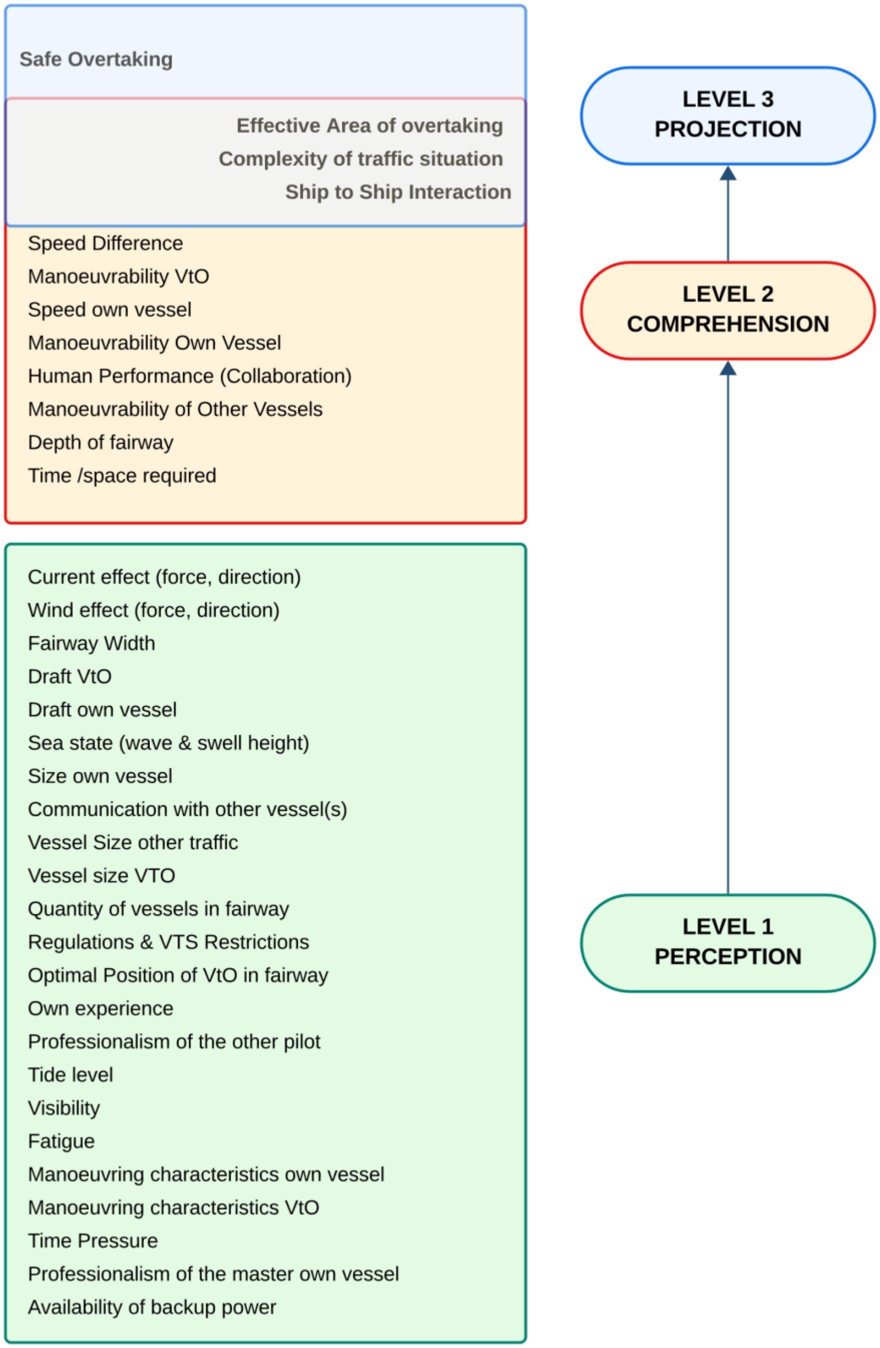


Figure 53 The factors of the FCM associated with the three levels of SA

It could be argued that the *Effective Area of overtaking* (C24), the *Complexity of Traffic Situation* (C25) and *Ship to Ship Interaction* (C26) could also be treated as level 3 SA concepts. This argument stems from the results of ACTA and the CDT (Table 4), where the description of the following three cognitive challenges can be linked to the factors C24, C25 and C26:

2. Determine if there is enough room to initiate overtaking - *Effective Area of overtaking* (C24)
3. Estimate how the traffic situation will evolve - *Complexity of Traffic Situation* (C25)
8. Determine the intensity of the hydrodynamic effects - *Ship to Ship Interaction* (C26)

C24 refers to the projected region where the overtaking will happen according to the calculations that occur during the comprehension of the situation that triggers overtaking. C25 is related to the future development of the traffic status that requires projection of working situations for all the involved vessels. C26 refers to one of the hydrodynamic effects that the vessel will experience in an overtaking situation (the other two being the Bank effect and the Squat effect). Additionally, the challenge "12. Plan ahead" is also directly related to level 3 SA as it refers to the aftermath of the overtaking maneuver, a result represented *by Safe Overtaking* (C1).

SAFE OVERTAKING	C1	The output factor, associated with how safe the overtaking manoeuvre will be
Effective Area of Overtaking	C24	The segment of the fairway where the overtaking will occur
Complexity of Traffic Situation	C25	The traffic congestion state of the fairway that increases the navigation difficulty
Ship to Ship Interaction	C26	The hydrodynamic interaction that occurs when the when the typical flow of water around the hull of the own vessel is constrained by the influence of the VtO

Following this approach, six cognitive challenges from the CDT (Table 4) may also be associated with comprehension (Level 2 SA) in a similar manner:

1. Calculate the speed difference with the forward vessel - *Speed Difference* (C23)
4. Communicate effectively with other ship and other actors - *Communication With Other Vessel(s)* - (C37)
7.Determine the effect of current - *Current Effect (Force, Direction)* (C2)
9.Calculate duration of overtaking - *Time /Space Required* (C27)
10.Maintain a safe speed - *Speed Own Vessel* (C9)
11.Maintain a safe passing distance - *Time /Space Required* (C27) and *Optimal Position of Vessel to Overtake in Fairway* (C19)

Current Effect (Force, Direction)	C2	The degree of the influence of the current, a continuous, directed movement of water, defined by force or speed and direction
Speed Own Vessel	C9	The speed at which the vessel is cruising at any moment, measured in knots (kn)
Optimal Position of Vessel to Overtake in Fairway	C19	In a narrow channel overtaking should normally take place on the port side[2] as the vessel being overtaken (VtO) should be as far as practicable on the starboard side of the channel, which indicates the optimal position
Speed Difference	C23	The difference between the speed of the overtaking vessel and speed of the vessel being overtaken
Time /Space Required	C27	The duration and area that are needed to perform overtaking with safety
Communication With Other Vessel(s)	C37	The effectiveness of communication between vessels that are involved in the overtaking situation

Even though factor *Current Effect (Force, Direction)* - (C2) is labelled as a transmitter concept in the FCM, the effect of the current participates in multiple calculations during pilotage and thus its perception alone is not enough. It could be argued that the factors of *Wind Effect (Force, Direction)* - (C3), *Sea State (Wave & Swell Height)* - (C4) and *Tide Level* - (C6) may be viewed in a similar manner as C2. Maintaining a safe passing distance can be linked to two factors, *Time /Space Required* - (C27) (especially the space required part) and *Optimal Position of Vessel to Overtake in Fairway* – (C19), as both participate in the mental equation for what a pilot comprehends as a safe passing distance. As pilots develop their situation awareness, they obtain the environmental information earlier and combine it with their experience and tacit knowledge that guides their strategic thinking for the overtaking situation:

" (The current) of course I observe, but I took into consideration before I made my decision, I knew the river area ahead of me has the special current situation, that I have currents changing directions in this area and then I know when I am passing buoy number X, the current will come from this side and two buoys further on the current will come from the other side. This is the river!" – WS1/ Participant 1

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[2] When looking forward, toward the bow of a ship, port and starboard refer to the left and right sides, respectively (NOOA, 2023)

The challenge “5.Combine information and cues from various sources” is concerned with the perception of all the information and cues that pilots need to decide, therefore it could be associated with Level 1 SA. The challenge “6. Collaborate with the other mariners (pilot, master, crew members)” is associated with the factors C33, C34, C35 and C36. Lastly, the challenge “4. Communicate effectively with other ship and other actors” is ostensibly associated with factor C37. These two challenges do not seem to be directly associated with any SA requirements but are involved with communication and collaboration that affect not only the perception of information (i.e. if the Master of the other vessel provides information on the ship status) but also the distributed SA of the system that affects the SA of the pilot. Details on collaboration and communication can be read in 4.6.4 Communication.

Human Performance (Collaboration)	C33	The effectiveness of the cooperation between mariners on board and inshore in relation to navigation
Own Experience	C34	The professional experience of the pilot on board the own vessel
Professionalism of The Master Own Vessel	C35	Associated with how excellent the master’s professional maritime skills are
Professionalism of The Other Pilot	C36	Associated with how excellent the professional maritime skills and experience of the pilot of the VtO are
Communication With Other Vessel(s)	C37	The effectiveness of communication between vessels that are involved in the overtaking situation

Finally, the challenge “5.Combine information and cues from various sources” involves the mental activity that blends acquired data input and is linked to all the transmitter factors associated with perception (Level 1 SA).

5.6.2 The effect of situation-specific factors

The current FCM is case specific, and the factors have no universal effect, but their value and effect depend on the type of the ship, the environmental conditions, the tide windows, and the fairway. Any change in these aspects will result in different weights and relationships. As P1 from WS1 said:

“I have an own ship situation. The draft is negative to the manoeuvrability. If I have more draft, it is worse for the manoeuvrability, less available sea area. Wind for example, if wind increases it is worse for

manoeuvrability, worse for the speed, so it's almost negative, for example if I have more speed, it is better for manoeuvrability so it's a plus, if I have less speed, it's negative for manoeuvrability."

Each fairway has its own special characteristics (factors *Fairway Depth (C7)*, *Fairway Width(C8)*) and the effect of the factors *Tide level*(C6) and Current Effect (C2) depend on the type of the ship.

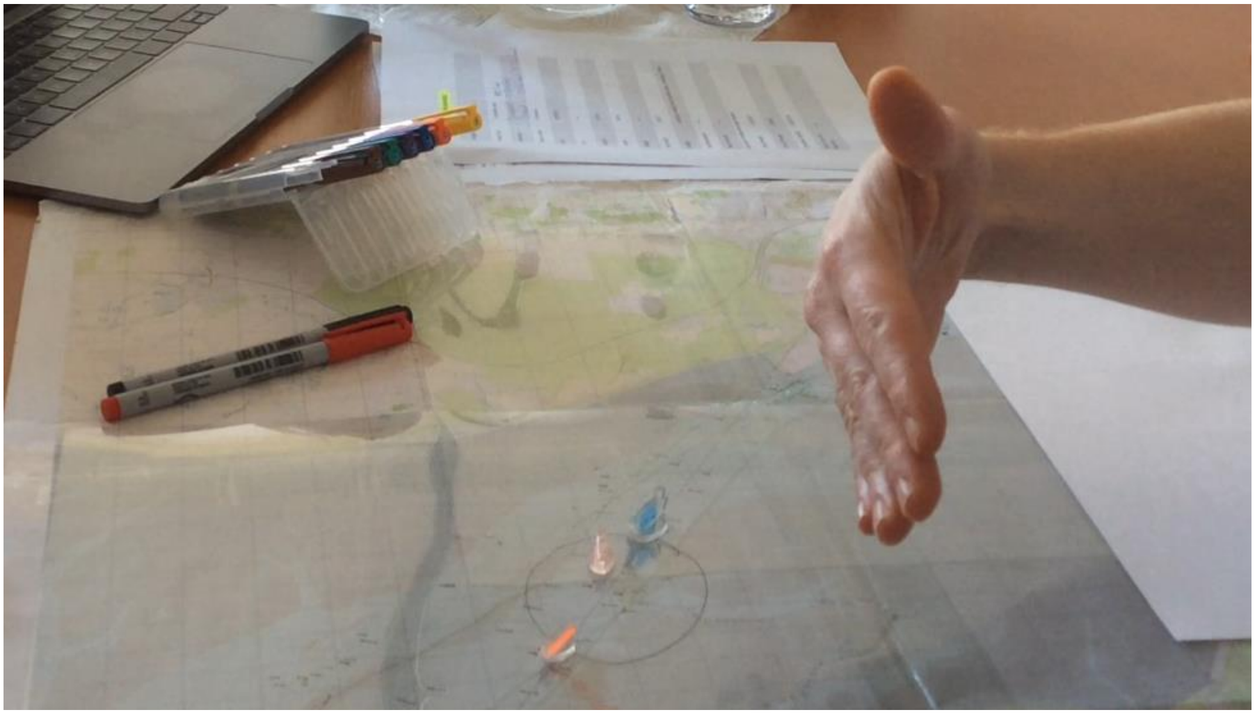


Figure 54: Participant 2 demonstrates how side wind will affect the heading of the vessel as it navigates though the fairway during Workshop 1.

The same can be said for other environmental factors. For instance, in WS1 the participants had the following exchange during the mapping session:

Participant 1: *"When I have wind from the side is more effective than from the front."*
Participant 2: "*And the current of course because we have some areas that have strong currents.*"

Based on the structural analysis, the *Current Effect* (C2) and the *Wind Effect* (C3) have the highest outdegree value (3.725 and 3.41 respectively). The number of connections they have to other factors (8 and 6 connections respectively) is also significant. The metrics and the connections number demonstrate how much influence these factors have in the overall situation. Sea State (C4) has also 6 outgoing links to other factors, however the level of outdegree is less (1.7). In a different scenario however, C4 would have a higher influence.

"Everything is influenced by the weather situation and also influences other ships because for example sea state, high sea, weather, small ship, I can have a small ship with fast small ship and then I have to see if it's high sea I cannot go as fast as I wish" - WS1/Participant 1

Further, the ship type (car carrier, container ship, research ship, passenger ship, fishing boat, and so on) can influence the manoeuvrability of each vessel (factors C13, C18, C21). This was emphasized by most participants in all the studies and the validation workshops:

"Bulk carriers are usually tankers, and they are very "lazy" in manoeuvring. A passenger ship well equipped with everything is manoeuvring easily, it is totally different" - WS1/Participant 1

"For example, passenger ship and a tanker, they are different type, but they definitely have different manoeuvre abilities. The passenger ship has, for example, propulsion and 10,000-kilowatt bow thrust and the tanker has a fixed propeller." – Validation WS- VP2

Therefore, pilots are asked to navigate by considering the inherent turning, yaw-checking, course-keeping and stopping abilities of their own ship, as well the similar characteristics of the other ships (factors C12, C17).

5.6.3 Collaboration and Communication

The pilots mentioned that there must be *collaboration* among the entities of the sociotechnical system to enable traffic situation. as expressed by the concept *Human Performance (Collaboration)* - (C33). There is a rule for overtaking (Rule 13 – COLREG) and according to pilots, if everyone follows the rule, nothing should happen. The overtaken vessel is required per regulation to slow down so that the overtaking vessel can pass faster and enable the manoeuvre. Another act of cooperation is to adjust the manoeuvring style, but not all pilots are willing to do so, according to WS1/Participant 2: *"Some pilots, if they are inbound, have not a problem to come close to the 'green side', and some others have a* *problem with it and will be more in the middle of the fairway."* The position of the vessels with respect to each other along the direction of motion is a contributing parameter to the level of the HI during navigation (DeMarco Muscat-Fenech et al. 2022).

Recently, the Netherlands' Maritime Disciplinary Court issued a decision on an incident involving a reefer overtaking a smaller, slower bulker that resulted in collision in September 2022. The court agreed with the inspector's report that the smaller vessel being overtaken was mostly to blame and believed that the first officer lacked situational awareness and did not react in an attempt to prevent the collision. A significant aspect of this incident is addition of a note calling special attention for vessels sailing at slow speeds in busy lanes and being approached from behind (The Maritime Executive 2023).

Although it is not highlighted in the structural analysis results, communication holds a key role in the successful collaboration. Even if the pilots and all the involved mariners strictly follow the rules, communication is not obligatory, as seen also in the discussion of the ACTA results. However good seamanship requires them to "*undertake all steps necessary to make this a safe manoeuvre".* All groups of participants agreed that contacting the other vessels and forming an agreement on the manoeuvre is positive and will increase the safety level.

Another noticeable observation is that the lack of communication might completely change the decision of a pilot to initiate the manoeuvre:

"If I can't communicate with one of these vessels, which is into this process, I wouldn't overtake because I make sure that everybody understands what we are doing and I need to address my wish to overtake to everybody in this complex situation, and if I can't reach one of them, I would stop overtaking." – Validation WS- VP2

Even when the pilot informs the forward vessel of their intentions, the master or the pilot on board any of the other vessels might also refuse to cooperate for several reasons:

"When I decide to overtake, I contact the ship and I inform the other captain 'I will overtake you' and then maybe it could happen that the captain says no, don't do it, because of X reasons" - *WS1/Participant 1*

5.6.4 Risks in overtaking and their mitigation

One significant danger in the studied scenario is a possible meeting between the three vessels (own vessel, vessel forward and vessel opposite) during the overtaking. This is reflected in the FCM by the factor *Effective Area of Overtaking* (C24) that refers to the segment of the fairway where the overtaking will occur. Participant 3 and Participant 4 in the Workshop 2 emphasized how important it is to avoid the hydrodynamic effects from possible interaction between three vessels that will occur if both outbound vessels (GUAYAQUIL and MARINO) are sailing to each other, and the inbound vessel (OTTAWA) is at the same time at the same position. The danger will be less if the small vessel keeps a course neat the buoy line, effectively giving more space to the bigger ships, especially the GUAYAQUIL to sail close to the centre of the fairway. Overall, however, this is a situation that all pilots want to avoid.

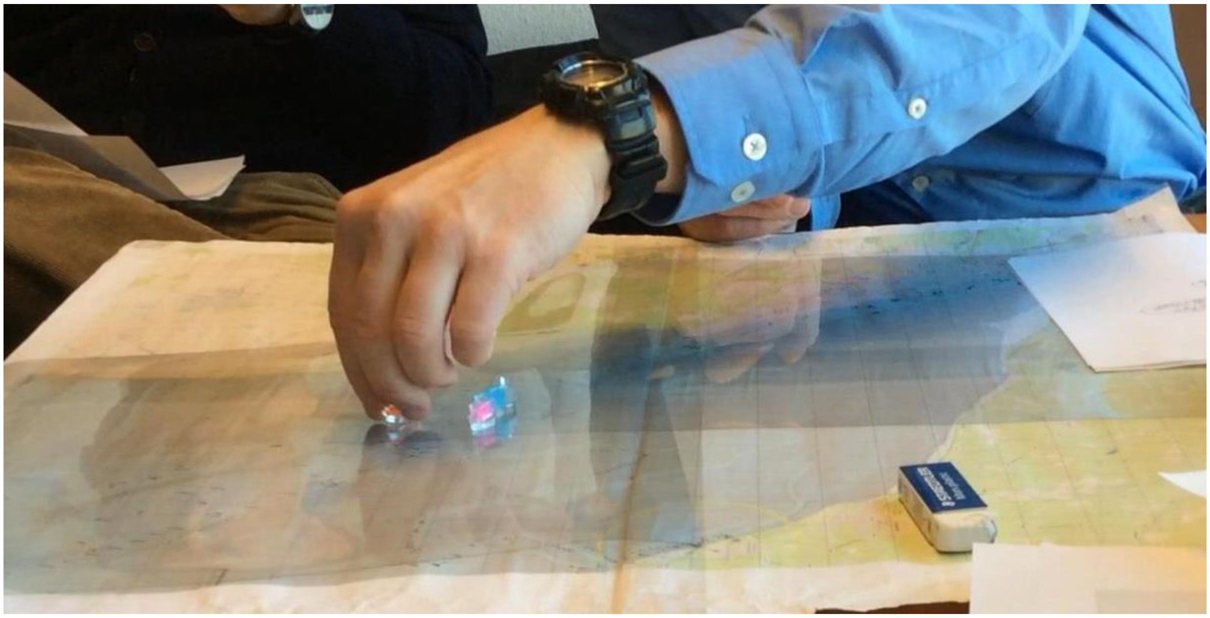


Figure 55: Participant 4 from Workshop 2 demonstrates on the map that it may be disastrous if all ships meet during overtaking, especially if his outbound vessel meets with the inbound vessel during the overtaking manoeuvre.

The dialogue between the two pilots in the WS2 is characteristic of the risk of such a meeting and the way to reduce it:

"P4: this is the meeting point (Figure 55). This is what I mean with the interaction between these two points.
P3: that is what we mean if we talk about finding out whether overtaking takes place. Because we want to know if it's overtaking whether both outbound vessels are next to each other and the inbound vessel is at the same time at the same position.
Researcher: that is very bad
P4: that is bad yes
P3: could be bad
P4: depending on the size. If the small vessel stays near the buoys and the GUAYAQUIL can stay in the center everything is nice"

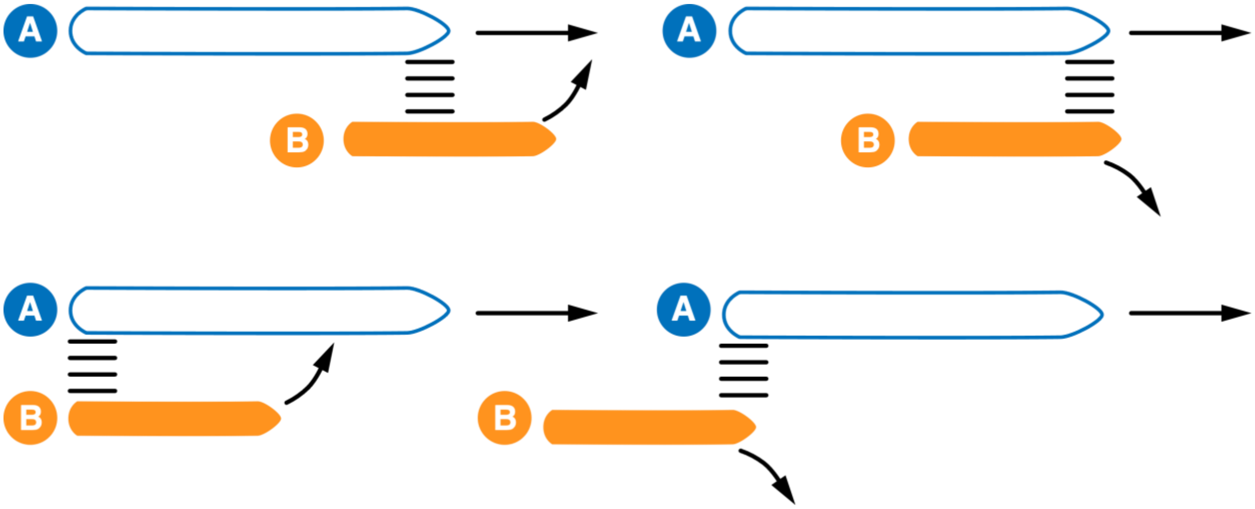


Figure 56: Ship to Ship Interaction between vessel 'A' (GUAYAQUIL) and vessel 'B' (MARINO) during overtaking in the studied scenario.

Speed difference (C23) is one of the most important factors affecting the decision-making activities and the execution of the overtaking manoeuvre with safety. The Ship to Ship Interaction (S2S interaction) strongly depends on the speed difference between the vessels. In the studied case, a Speed Difference of more than 4 knots may reduce the effect of S2S Interaction, as well as the duration and the distance of the fairway that the vessel needs to sail for the completion of the manoeuvre. S2S Interaction can increase the risk of accidents because during overtaking in a narrow channel, the ship handling is significantly impacted by its effects. Some of the consequences are the loss of the vessel's capability to change course, maintain a safe speed and distance to the shore and other vessels (Vantorre et al. 2017; Zhou et al. 2023). Therefore, as WS2/Participant 3 explained, *"if we have a high level of S2S interaction for a long period then it's a danger for the manoeuvre".*

Maintaining a safe speed is another significant operational and cognitive challenge for pilotage, for the overtaking and the overtaken vessel equally. Pilots pointed out that the speed is the main aspect they must observe, because in such scenarios when one of the three participating ships' speeds changes, the entire situation changes. If the speed of the overtaken ship decreases, it is beneficial to the overall situation and their decision to overtake and results in a faster operation. At the same time, a speed change may have an adverse effect on the opposing ship's manoeuvrability and consequently a negative impact on their decision to overtake. As WS1/Participant 1 said, *"When I see the other ship going slower and it is not manoeuvring better, then I must say maybe I do not overtake even if it's going slow. It could be both ways.".* This challenge was obvious in the accident between the RHONESTERN and the ZAPADNYY that was mentioned in the Introduction, where the report stated that *"it is impossible to make a statement with sufficient certainty as to whether a decision to increase or reduce speed after the onset of a hydrodynamic effect in this single case under consideration, would in fact have had limited the impact of the accident"* (BSU 2012).

An interesting observation was that the participants of this study did not view the *Restrictions and Regulations* (C32) as a negative factor. Even though it has a negative influence on the *Speed own Vessel* (C9), it is good for the concept of *Safe Overtaking* (C1). However, Butler et al (2022) have claimed that most professionals regard Regulations and Associations, and more specifically audits and inspections and supervision and enforcement in a negative light. Nevertheless, the findings of this study support the conclusion that incorrect decisions can have significant consequences for both the pilot and the maritime domain as a whole.

5.7 Scenario analysis and model calibration

Once an FCM model is built, increasing, or decreasing the value of the factors included in the model may allow us to examine different scenarios of change. It is also possible to ask "what–if" questions and run simulations to determine what state the system will go to under different conditions (Kosko 1993). FCM simulations can provide a more in-depth knowledge of concept behaviour as well as interactions in terms of how one concept influences others. The “what-if “scenarios that were used during the simulation interviews in the ACTA and FCM studies could be used to run model simulations and see the predicted state of each factor that is affected. By having a fixed state in certain factors, we can perform a quantitative assessment of the key concepts influence on the system (Papageorgiou 2014).

The proposed FCM has the distinguishable capability to assess the impact of different influences limited to some factors or customized to specific calculations. For instance, by activating one of the environmental factors in a scenario along with the associated ordinary components, a more sophisticated scenario analysis can be studied. The “what-if” scenario of the occurrence of strong wind can be simulated by using the Scenario tool of the Mental Modeler Suite. After importing the xml file, we can set the value of wind as 1 (maximum) in the model, choose the Sigmoid function, and the tool will run the Scenario. The results of the FCM are depicted in Figure 57. Table 13 describes the actual state of the affected components.

According to the predicted state of the factors, the *Speed* and *Manoeuvrability* of all vessels are expected to decrease, the *Speed Difference* between the own vessel and the VtO will increase, as well as the UKC. *Safe Overtaking* is predicted to decrease. These predictions and any future attempts should be checked once again with expert pilots to assess them and see if there is need for further calibration of the model, by manipulating the relationships and weights.

It is suggested that before the simulation process takes place, a baseline scenario needs to be conducted, where all concepts have the initial value of zero and results in the baseline ‘steady state’ of the model (Papageorgiou 2021). Then during the simulations, the dynamic change of the values of the concepts can assist in the quantitative interpretation of the impact of the most influential concepts on the model.

Scenario

Sigmoid

State Prediction:

	Component	+/-	Preferred State	Actual State
☑	Regulations & VTS Restrictions			
☑	Speed own vessel			Decrease
☑	Speed VtO			Decrease
☑	Current effect (force, direction)			
	Wind effect (force, direction)	1		
☑	Effective Area of overtaking			
☑	SAFE OVERTAKING			Decrease
☑	SPEED DIFFERENCE			Increase
☑	MANOEUVRABILITY OWN VESSEL			Decrease
☑	Communication with other vessel(s)			
☑	Draft own vessel			
☑	MANOEUVRABILITY VtO			Decrease
☑	COMPLEXITY OF TRAFFIC SITUATION			
☑	Speed of other vessels			Decrease
☑	MANOEUVRABILITY of OTHER VESSELS			Decrease

Figure 57: Percentage of change for affected concepts when the concept "Wind effect" is activated.

Factor	**Actual State**
Regulations & VTS Restrictions	
Speed own vessel	Decrease
Speed VtO	Decrease
Current effect (force, direction)	
Wind effect (force, direction)	
Effective Area of overtaking	
SAFE OVERTAKING	Decrease
SPEED DIFFERENCE	Increase
MANOEUVRABILITY OWN VESSEL	Decrease
Communication with other vessel(s)	
Draft own vessel	
MANOEUVRABILITY VtO	Decrease
COMPLEXITY OF TRAFFIC SITUATION	
Speed of other vessels	Decrease
MANOEUVRABILITY of OTHER VESSELS	Decrease
Vessel Size other traffic	
Depth of fairway	
SHIP TO SHIP INTERACTION	
Size own vessel	
Draft VtO	
Vessel size VTO	
Optimal Position of VtO in fairway	
HUMAN PERFORMANCE (collaboration)	
Own experience	
Time Pressure	
Professionalism of the master own vessel	
Professionalism of the other pilot	
Quantity of vessels in fairway	
Time /space required	
Availability of backup power	
Fairway Width	
Tide level	
Visibility	
Under Keel Clearance	Increase
Sea state (wave & swell height)	
Fatigue	
Manoeuvring characteristics own vessel	
Manoeuvring characteristics VtO	

Table 13: The predicted state of the model variables after the scenario simulation

5.8 Limitations and Challenges

Even though workshops with more than one participant are a great research method, they do have some limitations and challenges. Participatory mapping in groups does not always provide a safe environment for free conversation due to the observing eyes of the other participants. It can lead to groupthink (Kjærgaard and Jensen 2008), which is when one opinion is expressed, and other participants agree or are affected by it. Also, groups may allow for only a few people to talk, or in this case one participant, rather than hearing from all participants. This was observed in both workshops, where the more experienced pilot was more dominant in the conversation. In the WS1, the less experienced participant attempted to get inspiration from the more experienced one during the mapping session. In the WS2, P4 also tried to follow what the P3 was doing. In both mapping workshops there were struggles from the participants to understand at first the negative relationship between concepts and then how an increase in a concept value can result in a positive effect for the linked concept. The inexperience of the facilitator and the conversation in a non-native language between the participants and the facilitator might have been contributing parameters to these struggles.

The FCM study also shares similar limitations with the ones mentioned in the corresponding section for the ACTA study. The homogenous (professional, cultural, and national backgrounds) sample of participants from the same pilot station in Bremerhaven is one of the most important parameters that should not be ignored. Pilots in the ACTA study and pilots in the FCM study have the same training and experiences, therefore there are instantiations of results that are similar and in agreement with each other. The data collection was generated in a non-operational environment and under time pressure, due to the limited availability of the facilitator and the participants. In each FCM workshop, one of the pilots participated under time pressure as they were called on duty right after the mapping sessions were over. These issues might have affected the validity and the quality of the gathered data. One of the purposes of the validation workshop was to address these issues. By including participants from different pilot stations and other ports, the study managed to yield more credible results. Yet even those participants shared similar national and perhaps cultural backgrounds, therefore the generalization of the final results should be treated with caution.

Finally, the dynamic nature of the FCM has not been explored, because a baseline 'steady state' of the model has not been produced. This would require another workshop with different participants that would validate the simulation results and the dynamic change of the values of the concepts. Only then the FCM can be used for a quantitative interpretation of the impact of the most influential concepts on the model and a prediction of the value for the *Safe Overtaking* concept.

5.9 Practical Implications

Several practical implications can be drawn from this study. The outcomes of this study can be proposed by human factors experts to enhance the existing design of systems in respect to the cognitive attributes of decision making during pilotage. Similar to the practical implications of the ACTA results, the relationships between the factors can determine the informational needs and how they need to be combined to support the task of overtaking in a similar scenario. For example, the factors that influence *Speed difference* (*Current effect*, *Speed* indications of 3 participating vessels, *Availability Of Backup Power* and *Complexity Of Traffic*) can be organised in a manner that lessen the mental calculations during pilotage and follow the principles of Ecological Interface Design.

The FCM contains the key factors that affect safe overtaking according to pilots and can be suggested as a roadmap to the practitioners and researchers of SA and safety in critical manoeuvres. The main advantage of the produced FCM is its ability to graphically express the higher levels of SA. The model indicates a broader scope that includes not only informational elements or environmental and human factors but also mental calculations and other wide-ranging factors that shape the navigational practices. It also provides an organisation of the key cognitive computations for overtaking alongside the factors that shape their outcome. The structural properties and metrics of the FCM may assist in identifying the factors that have the greatest impact on the pilots' decision to overtake.

The FCM and the findings can provide input for the design of training and evaluation of pilots that operate in such settings as well as mariners who sail in restricted fairways, since not all ships employ the help of a pilot. Understanding the factors that affect decision making with regards to SA has had a positive impact in other domains and has already been suggested by many researchers in the marime domain (Hockey et al. 2003; Chauvin et al. 2013; Øvergård et al. 2014; Cordon et al. 2017; Sharma et al. 2019; Butler et al. 2022).

The findings can also contibute into understanding better the accidents and incidents that occur during pilotage, as long as the individual-centred pilotage is the prevailing paradigm in practice (Drouin et al.; Wild 2011; Lahtinen et al. 2020b). By tapping into the mental model of a pilot, we can have "access" to their thinking patterns and how they make projections about the evolution of the maneuver and their surroundings by comprehending the the cues and input from the instruments. Also, the dynamic nature of the FCM allows for simulating potential parameter changes that might occur during overtaking manoeuvres and forecast the outcome on the level of safe overtaking. Certain scenarios can be examined this way and it can be observed how the examined case responds to changes to the value of certain factors, with the help of expert navigators and stakeholders from the domain.

Chapter 6 Conclusions and Future Work

This chapter provides an overview of the key results and the major research contributions, the practical implications and the future research directions that have emerged from the work of this thesis.

6.1 Research contributions and Conclusions

During the last decades, human factors knowledge and skills started to get more attention into the maritime domain. Decision making during pilotage in critical manoeuvres can be cognitively challenging and many factors can influence the pilots who undertake this task. In this context, the motivation of this thesis was to understand the dynamic and complicated task domain of sea pilotage and to explore possible contributions in making navigation safer in demanding and critical manoeuvres.

For the completion of the thesis, three studies were conducted based on ergonomics methods. The first study used ethnographic approaches to explore maritime pilots' job responsibilities in the Bremerhaven port region's fairway and to create a case study for the facilitation of the further research. The second study proposed an approach that used an adaptation of ACTA to systematically examine the overtaking manoeuvre and to identify twelve different cognitive challenges that are relevant to the safety and effectiveness of the activity, along with a comprehension of the cognitive processes of mariners undertaking this duty in the Bremerhaven port region's fairway. The third study proposed an FCM-based modelling technique to create a cognitive model of the factors that marine pilots consider when making decisions and to represent how these factors impact safe overtaking. The outcomes of this thesis can be proposed to the human factors experts, system designers, mariners, as well as maritime regulation and training organisations to enhance the existing design of systems, training, and safety policies in respect to the cognitive attributes of decision-making during pilotage.

The first chapter described the scope of this thesis and introduced the context of decision-making during pilotage in demanding manoeuvres and the motivation of the thesis. It also outlined the aims and objectives of the thesis, the research questions and how these questions were explored in the following chapters.

The second chapter presented a broad and comprehensive literature review in the context of ship manoeuvring, maritime pilotage, hydrodynamic interaction in relation to overtaking situations. It also included an overview of the ship bridge systems, an account of the critical importance of decision-making in maritime and an analysis of human error and situation awareness in maritime. The third chapter presented the methodological approaches and related applications of the Applied Cognitive Task Analysis (ACTA) and the Fuzzy Cognitive Maps (FCM) technique. The content of chapters two and three formed the backbone of this thesis and served as the basis for the studies of the chapters four and five.

In chapter four, the domain familiarization and ACTA studies were presented. The chapter addressed the results and limitations of the two studies, as well as the study design and implementation technique, with a focus on ACTA. The domain familiarisation study contributed to the assessment of the pilotage practices and the ecological dimension of the working environment. The results of the ACTA study contributed 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. The results strengthened 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 helped uncover the most demanding parts of the pilots' job, since it is one of the most common and complicated encounters between vessels.

Moreover, the study results suggested 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 highlighted 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.

In chapter five, the FCM methodogy was used for the problem of safe overtaking in confined waters. The proposed approach employed participatory modeling workshops and the Mental Modeler tool to create and evaluate certain scenarios within the boundaries of the case study. This study demonstrated the efficacy of using FCM in modeling this type of problem due to its ability to incorporate knowledge from participants, synthesizing what they believe about a situation and then offering a graphical representation of their aggregated mental model. The final FCM is composed of 38 factors, including environmental, ship-related, traffic, human, and organisational aspects, as well as their interdependencies, which are represented by 82 relationships. Also, the metrics produced by the structural analysis of the FCM assisted in identifying the factors that have the greatest impact on the pilots' decision to overtake with safety, as well as concepts of particular interest. Finally, the chapter suggests further steps to exploit the dynamic aspects of the FCM that can enable scenario analysis and simulation but were not addressed in this thesis.

The FCM also provides an organisation of the key cognitive computations for overtaking alongside the factors that shape their outcome which may be used to represent the three levels of SA. The decision to overtake is situated in factors that are related to the SA levels 2 and 3 as defined by Endsley (1995), meaning comprehension of cues and projection of the future situation. The FCM is case specific, and the factors have no universal impact; their value and effect are dependent on the kind of ship, area, and environmental conditions. This strengthens the argument from the ACTA study that 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. Another significant observation is the role of collaboration and communication that adds to the conclusions from the ACTA study. Pilots of the FCM study claimed that contacting other vessels and reaching an agreement on how the procedure will be done and how each ship will sail is a positive step that increases safety. The results also support the findings presented in Chapter 4 in relation to the dominant goal of pilotage, which is to ensure the safety of navigation. This was reflected in the strategies pilots use to mitigate the risks of the hydrodynamic interactions and the control of the speed that may present challenges and results in consequences that are difficult to predict.

The conclusions drawn from both the ACTA and FCM studies highlight the distinct and case-specific nature of maritime pilotage. FCM findings emphasize that the impact of various factors is contingent on the specific ship, location, and environmental conditions. Pilots, as noted in the ACTA study, approach each situation as unique, emphasizing the need for meticulous preparation, purposeful communication, and professional respect in interactions with other mariners. Efficient communication, whether mandatory or optional, is deemed essential for safety, involving measures such as contacting other vessels, seeking confirmation, and resolving uncertainties through cooperation. The primary objective of pilotage, as reiterated in both studies, is to ensure the safety of navigation. Additionally, the studies underline the significance of preparation and management, as highlighted by Mikkers et al. (2012) and Sharma et al. (2019), in creating extra safety margins and emphasizing the critical role of planning in the pilotage process.

The results of both studies used in tandem can improve the understanding of the cognitive aspects of the overtaking situation and help researchers combine content (ACTA) and structural (FCM) knowledge. The CDT and the FCM can serve as tools in situation-based analyses of the work on board ship bridges in relation to design of technology, accident investigation or the development of training procedures. They can form the basis for the design of systems that can support pilots and other navigators in developing SA by providing support for the Cognitive Demands and the factors that affect Safe Overtaking. For example, they can inform preliminary design choices on the type of warning system and aspects of warning strategies of instruments such as the PPU, RADAR, ECDIS, conning display and more. The findings can also indicate what trends can be presented over time to help mariners project the future state of the situation. Moreover, they can also be used to help in the evaluation of existing and future artifacts for ship bridges and suggest design principles that will mitigate the differences in interfaces that hinder mariners from developing SA (Sandhåland et al. 2015).

In relation to training, the outputs of this thesis can contribute to the development of non-technical training. In the maritime domain, where human activities are safety critical, non-technical training might be secondary to the technical training of the mariners. However, the results indicate that it should represent a regulatory requirement, as seen from the benefits in aviation (Cacciabue 2004, p.119).

Also, the findings on the cognitive aspects of decision making in pilotage and their relation to SA as discussed in this thesis may help to better describe and understand maritime pilotage accidents or incidents by defining scenarios for testing and evaluating the systems. The findings can also indicate design guidelines that will better support the SA of the pilots since they have uncovered how pilots obtain, build, or lose SA during overtaking. The goal is to present the cues and information in a manner that matches with the cognitive model of the pilots and mitigates the cognitive challenges so that they will remain in control of the situation.

6.2 Publications

Part of the current work has been/is published as:

1. Parisi Stella and Nathanael Dimitris. (under review) 2023. Identifying key cognitive challenges for safe ship overtaking in restricted waterways. Cognition Technology Work, Springer. https://doi.org/10.21203/rs.3.rs-2789944/v1

2. Stella Parisi and Dimitris Nathanael. 2019. Adapting Applied Cognitive Task Analysis to identify cognitive challenges in sea pilotage. In Proceedings of the 31st European Conference on Cognitive Ergonomics (ECCE '19). Association for Computing Machinery, New York, NY, USA, 69–74. https://doi.org/10.1145/3335082.3335096

3. Stella Parisi and Martin Fränzle. 2017. Navigating with safety in confined waterways: an explorative case study. In: Burghardt, M., Wimmer, R., Wolff, C. & Womser-Hacker, C. eds., Mensch und Computer 2017 - Workshopband.Gesellschaft für Informatik e.V., Regensburg, Germany.

4. Stella Parisi and Andreas Lüdtke. 2016. Evaluation of Distributed Situation Awareness on a Ship Bridge. In Proceedings of the European Conference on Cognitive Ergonomics (ECCE '16). Association for Computing Machinery, New York, NY, USA, Article 34, 1–2. https://doi.org/10.1145/2970930.2970965

6.3 Future research

6.3.1 Creation of additional FCM models

The FCM model that was presented in this thesis depicts the mental model of pilots for a specific case study. New FCM models for different participant groups may be constructed to offer further insights. FCM models from other pilot stations in regions with similar fairway characteristics (for example Hamburg, Kiel, etc) can be designed following a similar approach. The comparison of FCMs may reveal similarities and deviations in the mental models of different working groups with respect to safety critical manoeuvres. Human factors researchers may employ FCM comparison to discover trends in reasoning identified through common aspects from the structure of the FCMs, that may be applied later to quantify the degree of conceptual agreement. Shared knowledge is important to fostering trust, interaction and collaboration between individual mariners and organisations, and FCMs can help in this direction by demonstrating the degree of shared knowledge (Gray et al. 2012; Kontogianni et al. 2012).

While overtaking is itself a challenging navigation act, other manoeuvres such as berthing and unberthing situations with or without tug assistance, tow turning, safe passage with withdrawal, turn and entry, embarking and disembarking pilots, person overboard accidents, etc could benefit from the creation of an FCM. These navigational acts are typical situations for application of manoeuvring assistance and decision support, where situation-dependent manoeuvring data can improve operational risk management and assist in situation dependent alarm thresholds for triggering collision warnings (Baldauf et al. 2011).

Metrics that are produced from the structural analysis uncover shared knowledge structure by measuring discrete dimensions of an individual's mental model structure, thereby permitting comparisons across individuals and groups. While this thesis did not produce another FCM, the results can form a baseline for future comparisons. The calculation of these measures allows the degree of shared knowledge to become estimated when the FCM modeling activity is standardized across individuals or groups.

6.3.2 Development of Digital twins

A digital twin can play a significant role in enhancing the safety of a vessel. Digital twins are more than just digital replicas of physical systems. In addition to sensor updates, the digital twin must match the physical asset's present reality (Jones et al. 2020). It can assist sea pilots and ship bridge crews in maintaining and building situational awareness by providing them with real-time, comprehensive, and visual information about the vessel. It can also be used in simulation training by helping inexperienced mariners to visualize and understand how the vessel will respond to different hydrodynamic forces and interactions.

Digital twins can continuously monitor the vessel's behaviour and environmental conditions, including currents, waves, and nearby vessels. By analysing real-time data, they can predict potential hydrodynamic interaction risks and provide early warnings to the crew. They have the ability to create accurate simulations of the vessel's hydrodynamic behaviour, taking into account its manoeuvring capabilities, size, type, and current conditions. Such an ability could be integrated in the collision avoidance systems of the ships by suggesting evasive manoeuvres or course adjustments.

Bibliography

Adumene S, Afenyo M, Salehi V, William P (2022) An adaptive model for human factors assessment in maritime operations. Int J Ind Ergon 89:103293. https://doi.org/10.1016/j.ergon.2022.103293

Aju kumar VN, Gandhi MS, Gandhi OP (2015) Identification and Assessment of Factors Influencing Human Reliability in Maintenance Using Fuzzy Cognitive Maps. Qual Reliab Eng Int 31:169–181. https://doi.org/10.1002/qre.1569

Akten N (2004) Analysis of Shipping Casualties in the Bosphorus. J Navig 57:345–356. https://doi.org/10.1017/S0373463304002826

Andresen M, Domsch ME, Cascorbi AH (2007) Working Unusual Hours and Its Relationship to Job Satisfaction: A Study of European Maritime Pilots. https://doi.org/10.1007/s12122-007-9010-5

Asadzadeh SM, Azadeh A, Negahban A, Sotoudeh A (2013) Assessment and improvement of integrated HSE and macroergonomics factors by fuzzy cognitive maps: The case of a large gas refinery. J Loss Prev Process Ind 26:1015–1026. https://doi.org/10.1016/j.jlp.2013.03.007

Australian Maritime Safety Authority (AMSA) (2020) Close proximity manoeuvres and overtaking situations in coastal pilotage areas—advisory note. https://www.amsa.gov.au/safety-navigation/navigating-coastal-waters/close-proximity-manoeuvres-and-overtaking-situations. Accessed 10 Oct 2022

Aydin M, Akyuz E, Turan O, Arslan O (2021) Validation of risk analysis for ship collision in narrow waters by using fuzzy Bayesian networks approach. Ocean Eng 231:108973. https://doi.org/10.1016/j.oceaneng.2021.108973

Axelrod R (1976) The Structure of Decision: Cognitive Maps of Political Elites. Princeton University Press.

Baker C, McCafferty D (2005) Accident database review of human-element concerns: What do the results mean for classification? In: RINA, Royal Institution of Naval Architects International Conference - Human Factors in Ship Design, Safety and Operation. Royal Institute of Naval Architects, London, pp 65–71

Baldauf M, Benedict K, Fischer S, et al (2011) e-Navigation and situation-dependent manoeuvring assistance to enhance maritime emergency response. WMU J Marit Aff 10:209. https://doi.org/10.1007/s13437-011-0014-x

Benedict K, Kirchhoff M, Gluch M, et al (2016) Simulation-Augmented Methods for Safe and Efficient Manoeuvres in Harbour Areas. TransNav, Int J Mar Navig Saf Sea Transp 10:193–201. https://doi.org/10.12716/1001.10.02.02

Berg HP (2013) Human Factors and Safety Culture in Maritime Safety (revised). TransNav, Int J Mar Navig Saf Sea Transp 7:343–352. https://doi.org/10.12716/1001.07.03.04

Bertolini M (2007) Assessment of human reliability factors: A fuzzy cognitive maps approach. Int J Ind Ergon 37:405–413. https://doi.org/10.1016/j.ergon.2005.12.009

Bertolini M, Bevilacqua M (2010) Fuzzy cognitive maps for human reliability analysis in production systems. Stud Fuzziness Soft Comput 252:381–415. https://doi.org/10.1007/978-3-642-12052-7_16

Bertram V (2012) Chapter 6 - Ship Maneuvering. In: Bertram V (ed) Practical Ship Hydrodynamics (Second Edition), Second Edi. Butterworth-Heinemann, Oxford, pp 241–298

Bevilacqua M, Ciarapica FE, Mazzuto G (2012) Analysis of injury events with fuzzy cognitive maps. J Loss Prev Process Ind 25:677–685. https://doi.org/10.1016/j.jlp.2012.02.004

Blacketer MP, Brownlee MTJ, Baldwin ED, Bowen BB (2021) Fuzzy Cognitive Maps of Social-Ecological Complexity: Applying Mental Modeler to the Bonneville Salt Flats. Ecol Complex 47:100950. https://doi.org/10.1016/j.ecocom.2021.100950

Bougon M, Weick K, Binkhorst D (1977) Cognition in Organizations: An Analysis of the Utrecht Jazz Orchestra. Adm Sci Q

22:606. https://doi.org/10.2307/2392403

Brödje A, Lützhöft M, Dahlman J (2010) The Whats, Whens, Whys and Hows of VTS Operator use of Sensor Information. In: International Conference on Human Performance at Sea. Glascow, Scotland, pp 161–172

Brodje A, Prison J, Jenvald J, Dahlman J (2011) Applied Cognitive Task Analysis as a tool for analyzing work demands in a C41 environment : a case study using a mid-fidelity simulation. In: de Waard D, Gérard N, Onnasch L, et al. (eds) Human Centred Automation. Shaker Publishing, Maastricht, the Netherlands, pp 313–326

Buche C, Chevaillier P, Nédélec A, et al (2010) Fuzzy cognitive maps for the simulation of individual adaptive behaviors. Comput Animat Virtual Worlds 21:573–587. https://doi.org/10.1002/cav.363

Bundesstelle für Seeunfalluntersuchung (2022) Federal Bureau of Maritime Casualty Investigation https://www.bsu-bund.de/SharedDocs/pdf/EN/Investigation_Report/2012/Investigation_Report_102_11.pdf?__blob=publicationFile&v=1 Accessed 29 May 2017

Butler GL, Read GJM, Salmon PM (2022) Understanding the systemic influences on maritime pilot decision-making. Appl Ergon 104:103827. https://doi.org/10.1016/j.apergo.2022.103827

Cacciabue PC (2004) Guide to Applying Human Factors Methods : Human Error and Accident Management in Safety-Critical Systems

Chakrabarty A (2021) How Squat, Bank and Bank Cushion Effects Influence Ships in Restricted Waters? In: Mar Insight. https://www.marineinsight.com/marine-navigation/how-squat-bank-and-bank-cushion-effects-influence-ships-in-restricted-waters/. Accessed 19 Oct 2022

Chambers TP, Main LC (2015) Symptoms of fatigue and coping strategies in maritime pilotage. Int Marit Health 66:43–48. https://doi.org/10.5603/IMH.2015.0011

Chauvin C, Clostermann JP, Hoc J-M (2008) Situation Awareness and the Decision-Making Process in a Dynamic Situation: Avoiding Collisions at Sea. J Cogn Eng Decis Mak 2:1–23. https://doi.org/10.1518/155534308X284345

Chauvin C, Lardjane S (2008) Decision making and strategies in an interaction situation: Collision avoidance at sea. Transp Res Part F Traffic Psychol Behav 11:259–269. https://doi.org/10.1016/j.trf.2008.01.001

Chauvin C, Lardjane S, Morel G, et al (2013) Human and organisational factors in maritime accidents: Analysis of collisions at sea using the HFACS. Accid Anal Prev 59:26–37. https://doi.org/10.1016/j.aap.2013.05.006

Cheah W-P, Kim K-Y, Yang H-J, et al (2008) Fuzzy Cognitive Map and Bayesian Belief Network for Causal Knowledge Engineering: A Comparative Study. KIPS Trans 15B:147–158. https://doi.org/10.3745/KIPSTB.2008.15-B.2.147

Cordon JR, Mestre JM, Walliser J (2017) Human factors in seafaring: The role of situation awareness. Saf Sci 93:256–265. https://doi.org/10.1016/j.ssci.2016.12.018

Craig C, Klein MI, Griswold J, et al (2012) Using Cognitive Task Analysis to Identify Critical Decisions in the Laparoscopic Environment. Hum Factors J Hum Factors Ergon Soc 54:1025–1039. https://doi.org/10.1177/0018720812448393

Darbra RM, Crawford JFE, Haley CW, Morrison RJ (2007) Safety Culture and Hazard Risk Perception of Australian and New Zealand Maritime Pilots 1. Mar Policy 31:736–745. https://doi.org/https://doi.org/10.1016/j.marpol.2007.02.004

de Vries L (2017) Work as Done? Understanding the Practice of Sociotechnical Work in the Maritime Domain. J Cogn Eng Decis Mak 11:270–295. https://doi.org/10.1177/1555343417707664

DeMarco Muscat-Fenech C, Sant T, Zheku VV, et al (2022) A Review of Ship-to-Ship Interactions in Calm Waters. J Mar Sci Eng 10:. https://doi.org/10.3390/jmse10121856

Dikopoulou Z (2021) Fuzzy Cognitive Maps. pp 27–42

Dikopoulou Z, Nápoles G, Papageorgiou E, Vanhoof K (2017) A Modified Fuzzy TOPSIS Method Aggregating 8.921 Partial Rankings For Companies' Attractiveness. pp 59–71

Dikopoulou Z, Papageorgiou E, Jetter A, Bochtis D (2018) Open source tool in R language to estimate the inference of the Fuzzy Cognitive Map in environmental decision making

Douali N (2015) Clinical Decision Support System based on Fuzzy Cognitive Maps. J Comput Sci Syst Biol 8:112–120.

https://doi.org/10.4172/jcsb.1000177

Downes P, Collins D (2021) Examining the Roles and Consequent Decision-Making Processes of High-Level Strength and Conditioning Coaches. Societies 11:76. https://doi.org/10.3390/soc11030076

Dreyfus HL (1999) The Primacy of Phenomenology over Logical Analysis. Philos Top 27:3–24

Drouin, P., & Heath, R. (2009). The pilotage paradigm: the need for a paradigm shift. Seaways.

Drury JL, Darling E (2007) A "Thin-Slicing" Approach to Understanding Cognitive Challenges in Complex Command and Control. Knowl Creat Diffus Util 12

Drury JL, Darling E (2008) A "Thin-Slicing" Approach to Understanding Cognitive Challenges in Real-time Command and Control. J Battlef Technol 11:9

Du P, Ouahsine A, Sergent P (2018) Influences of the separation distance, ship speed and channel dimension on ship maneuverability in a confined waterway. Comptes Rendus Mécanique 346:390–401. https://doi.org/10.1016/J.CRME.2018.01.005

Eden C (1992) ON THE NATURE OF COGNITIVE MAPS. J Manag Stud 29:261–265. https://doi.org/10.1111/j.1467-6486.1992.tb00664.x

EMPA - European Maritime Pilots' Association EMPA Recommendation on Pilots' Training. http://empa-pilots.eu/empa-recommendation-on-pilotsa-training. Accessed 20 Mar 2022

Endsley MR (1995) Toward a Theory of Situation Awareness in Dynamic Systems. Hum Factors J Hum Factors Ergon Soc 37:32–64. https://doi.org/10.1518/001872095779049543

Endsley MR (2012) Designing for Situation Awareness, Second. CRC Press, Boca Raton, FL

Engome Tchupo D, Macht GA (2022) Comparing fuzzy cognitive maps: Methods and their applications in team communication. Int J Ind Ergon 92:103344. https://doi.org/10.1016/j.ergon.2022.103344

Ernstsen J, Nazir S (2018) Human Error in Pilotage Operations. TransNav, Int J Mar Navig Saf Sea Transp 12:49–56. https://doi.org/10.12716/1001.12.01.05

Gore J, Banks AP, McDowall A (2018) Developing cognitive task analysis and the importance of socio-cognitive competence/insight for professional practice. Cogn Technol Work 20:555–563. https://doi.org/10.1007/s10111-018-0502-2

Gray S, Shwom R, Jordan R (2012) Understanding Factors That Influence Stakeholder Trust of Natural Resource Science and Institutions. Environ Manage 49:663–674. https://doi.org/10.1007/s00267-011-9800-7

Gray SA, Gray S, Kok JL De, et al (2015) Using fuzzy cognitive mapping as a participatory approach to analyze change, preferred states, and perceived resilience of social-ecological systems. Ecol Soc 20:11. https://doi.org/10.5751/ES-07396-200211

Gray SA, Zanre E, Gray SRJ (2014) Fuzzy Cognitive Maps for Applied Sciences and Engineering. Springer Berlin Heidelberg, Berlin, Heidelberg

Graziano A, Teixeira AP, Guedes Soares C (2016) Classification of human errors in grounding and collision accidents using the TRACEr taxonomy. Saf Sci 86:245–257. https://doi.org/10.1016/j.ssci.2016.02.026

Grech MR, Horberry T, Smith A (2002) Human Error in Maritime Operations: Analyses of Accident Reports Using the Leximancer Tool. Proc Hum Factors Ergon Soc Annu Meet 46:1718–1721. https://doi.org/10.1177/154193120204601906

Grech MR, Horberry TJ, Koester T (2019) HUMAN FACTORS in the MARITIME DOMAIN, 1st Editio. CRC Press, Boca Raton, FL

Grech MR, Lemon N (2015) Human Centred Design for Enhanced Navigation Systems : Shifting the Focus on User Needs. In: Pacific 2015 International Maritime Conference. Sydney

Haffaci K, Massicotte MC, Doyon-Poulin P (2021) Goal-Directed Task Analysis for Situation Awareness Requirements During Ship Docking in Compulsory Pilotage Area. Springer International Publishing

Hamburg Pilot Association The first three "harbour pilots" – 1858. https://www.hamburg-pilot.de/Halo_RESTART/Halo_EN/History.html#image1-1e. Accessed 12 Feb 2019

Harary, F., Norman, R.Z., Cartwright, D., 1965. Structural Models: An Introduction to the Theory of Directed Graphs. John Wiley & Sons, New York.

Hasbullah M, Paroka D, Rosmani, Hanisa (2019) Study on the Characteristics of Maneuvering Ferry Vessel as Effect of the Sea Waves. IOP Conf Ser Mater Sci Eng 676:012023. https://doi.org/10.1088/1757-899X/676/1/012023

Hockey GRJ, Healey A, Crawshaw M, et al (2003) Cognitive Demands of Collision Avoidance in Simulated Ship Control. Hum Factors J Hum Factors Ergon Soc 45:252–265. https://doi.org/10.1518/hfes.45.2.252.27240

Hoffman RR (1987) The problem of extracting the knowledge of experts from the perspective of experimental psychology. AI Mag 8:53

Hoffman RR, Coffey JW, Ford KM, Carnot MJ (2001) Storm-LK: A Human-Centered Knowledge Model for Weather Forecasting. Proc Hum Factors Ergon Soc Annu Meet 45:752–752. https://doi.org/10.1177/154193120104500807

Hoffman RR, Lintern G (2006) Eliciting and Representing the Knowledge of Experts. In: The Cambridge Handbook of Expertise and Expert Performance. Cambridge University Press, pp 203–222

Hutchins E (Bradford Books) Edwin Hutchins-Cognition in the Wild-The MIT Press (1995).pdf

IMPA - International Maritime Pilots' Association IMO & Pilotage. https://www.impahq.org/imo-pilotage. Accessed 24 Mar 2022

Inoue K (2000) Evaluation method of ship-handling difficulty for navigation in restricted and congested waterways. J Navig 53:167–180. https://doi.org/10.1017/S0373463399008541

International Maritime Organization Pilotage. https://www.imo.org/en/OurWork/Safety/Pages/Pilotage.aspx. Accessed 24 Mar 2022

Irani Z, Sharif AM, Papadopoulos T (2015) Organizational Energy: A Behavioral Analysis of Human and Organizational Factors in Manufacturing. IEEE Trans Eng Manag 62:193–204. https://doi.org/10.1109/TEM.2015.2402215

Jetter AJ, Kok K (2014) Fuzzy Cognitive Maps for futures studies-A methodological assessment of concepts and methods. Futures 61:45–57. https://doi.org/10.1016/j.futures.2014.05.002

Jiang G, Tian Z, Jiang T (2014) Using Fuzzy Cognitive Maps to Analyze the Information Processing Model of Situation Awareness. In: 2014 Sixth International Conference on Intelligent Human-Machine Systems and Cybernetics. pp 245–248

Jones D, Snider C, Nassehi A, et al (2020) Characterising the Digital Twin: A systematic literature review. CIRP J Manuf Sci Technol 29:36–52. https://doi.org/10.1016/j.cirpj.2020.02.002

Jones RET, Connors ES, Mossey ME, et al (2011) Using fuzzy cognitive mapping techniques to model situation awareness for army infantry platoon leaders. Comput Math Organ Theory 17:272–295. https://doi.org/10.1007/s10588-011-9094-6

Kjærgaard A, Jensen TB (2008) Appropriation of information systems: Using cognitive mapping for eliciting users' sensemaking; [Appropriation des systèmes d'information: Utiliser les cartes cognitives pour révéler le sensemaking des utilisateurs]. In: ICIS 2008 Proceedings - Twenty Ninth International Conference on Information Systems

Klein GA, Calderwood R, Macgregor D (1989) Critical decision method for eliciting knowledge. IEEE Trans Syst Man Cybern 19:462–472

Klein GA, Orasanu J, Calderwood R, Zsambok CE (1993) Decision making in action: Models and methods, Klein, G.A., Orasanu, J., Calderwood, R. and Zsambok, C.E. (eds). Norwood, NJ: Ablex, 1993, 480 pp. ISBN 0–89391–794–X (pb). Norwood, New Jersey

Kokkinos K, Lakioti E, Papageorgiou E, et al (2018) Fuzzy Cognitive Map-Based Modeling of Social Acceptance to Overcome Uncertainties in Establishing Waste Biorefinery Facilities. Front Energy Res 6:. https://doi.org/10.3389/fenrg.2018.00112

Kontogianni AD, Papageorgiou EI, Tourkolias C (2012) How do you perceive environmental change? Fuzzy Cognitive

Mapping informing stakeholder analysis for environmental policy making and non-market valuation. Appl Soft Comput 12:3725–3735. https://doi.org/10.1016/j.asoc.2012.05.003

Kosko, B. (1994). *The new science of fuzzy logic*. HarperCollins.

Kosko B (1986) Fuzzy cognitive maps. Int J Man Mach Stud 24:65–75. https://doi.org/10.1016/S0020-7373(86)80040-2

Kosko B (1993) ADAPTIVE INFERENCE IN FUZZY KNOWLEDGE NETWORKS. In: Readings in Fuzzy Sets for Intelligent Systems. Elsevier, pp 888–891

Lahtinen J, Valdez Banda OA, Kujala P, Hirdaris S (2020a) The Risks of Remote Pilotage in an Intelligent Fairway – preliminary considerations. In: Proceedings of the International Seminar on Safety and Security of Autonomous Vessels (ISSAV) and European STAMP Workshop and Conference (ESWC) 2019. Sciendo, pp 48–57

Lahtinen J, Valdez Banda OA, Kujala P, Hirdaris S (2020b) Remote piloting in an intelligent fairway – A paradigm for future pilotage. Saf Sci 130:104889. https://doi.org/10.1016/j.ssci.2020.104889

Langard B, Morel G, Chauvin C (2015) Collision risk management in passenger transportation: A study of the conditions for success in a safe shipping company. Psychol Française 60:111–127. https://doi.org/10.1016/j.psfr.2014.11.001

Lappalainen J, Kunnaala V, Tapaninen U (2014) Present pilotage practices in Finland. WMU J Marit Aff 13:77–99. https://doi.org/10.1007/s13437-013-0055-4

Latorella K, Pliske R, Hutton R, Chrenka J (2001) Cognitive Task Analysis of Business Jet Pilots ' Weather Flying Behaviors : Preliminary Results

Lazakis I, Ölçer A (2016) Selection of the best maintenance approach in the maritime industry under fuzzy multiple attributive group decision-making environment. Proc Inst Mech Eng Part M J Eng Marit Environ 230:297–309. https://doi.org/10.1177/1475090215569819

Lazar J, Feng JH, Hochheiser H (2010) Research methods in human-computer interaction

Lee C-K, Lee S-G (2008) Mechanical Science and Technology Investigation of ship maneuvering with hydrodynamic effects between ship and bank. J Mech Sci Technol 22:1230–1236. https://doi.org/10.1007/s12206-008-0309-9

Lee JD, Sanquist TF (2000) Augmenting the operator function model with cognitive operations: assessing the cognitive demands of technological innovation in ship navigation. IEEE Trans Syst Man, Cybern - Part A Syst Humans 30:273–285. https://doi.org/10.1109/3468.844353

Lercel D, Andrews DH (2021) Cognitive Task Analysis of Unmanned Aircraft System Pilots. Int J Aerosp Psychol 31:1–24. https://doi.org/10.1080/24721840.2021.1895797

Leveson NG (2011) Engineering a Safer World: Systems Thinking Applied to Safety. The MIT Press, Cambridge

Lützhöft M, Dekker SWA (2002) On your watch: Automation on the bridge. J Navig 55:83–96. https://doi.org/10.1017/S0373463301001588

Ma L, Ma X, Lan H, et al (2022) A data-driven method for modeling human factors in maritime accidents by integrating DEMATEL and FCM based on HFACS: A case of ship collisions. Ocean Eng 266:112699. https://doi.org/10.1016/j.oceaneng.2022.112699

Mansson JT, Lutzhoft M, Brooks B (2017) Joint Activity in the Maritime Traffic System: Perceptions of Ship Masters, Maritime Pilots, Tug Masters, and Vessel Traffic Service Operators. J Navig 70:547–560. https://doi.org/10.1017/S0373463316000758

Martindale A, Collins D, Morton V (2017) Cognition at the crime scene: Identifying cognitive demands on professional judgement & decision making expertise of crime scene examiners. In: Gore J, Ward P (eds) Proceedings of the 13th Bi-annual International Conference on Naturalistic Decision Making. The University of Bath, Bath, UK, pp 226–230

McAndrew C, Gore J (2013) Understanding Preferences in Experience-Based Choice. J Cogn Eng Decis Mak 7:179–197. https://doi.org/10.1177/1555343412463922

Mei S, Zhu Y, Qiu X, et al (2014) Individual Decision Making Can Drive Epidemics: A Fuzzy Cognitive Map Study. IEEE Trans Fuzzy Syst 22:264–273. https://doi.org/10.1109/TFUZZ.2013.2251638

Mendoza GA, Prabhu R (2009) Evaluating multi-stakeholder perceptions of project impacts: a participatory value-based multi-criteria approach. Int J Sustain Dev World Ecol 16:177–190. https://doi.org/10.1080/13504500902919672

Mikkers M, Henriqson E, Dekker S (2012) Managing multiple and conflicting goals in dynamic and complex situations: Exploring the practical field of maritime pilots. J Marit Res 9:13–18

Militello LG, Hutton RJB (1998) Applied cognitive task analysis (ACTA): a practitioner's toolkit for understanding cognitive task demands. Ergonomics 41:1618–1641. https://doi.org/10.1080/001401398186108

Minotra D, Feigh K (2017) Eliciting Knowledge from Helicopter Pilots: Recommendations for Revising the ACTA Method for Helicopter Landing Tasks. Proc Hum Factors Ergon Soc Annu Meet 61:242–246. https://doi.org/10.1177/1541931213601544

Morozova G, Martindale A, Currie I (2017) Identifying the cognitive demands on experts' decision making in liver transplantation. In: Gore J, Ward P (eds) Proceedings of the 13th Bi-annual International Conference on Naturalistic Decision Making. The University of Bath, Bath, UK, pp 241–246

National Research Council (1994) Minding the Helm. National Academies Press, Washington, D.C.

National Transportation Safety Board (2015) Marine Accident Brief: Collision between Tanker Chembulk Houston and Container Ship Monte Alegre. Washington, DC United States

Navas de Maya B, Kurt RE (2020) Marine Accident Learning with Fuzzy Cognitive Maps (MALFCMs): A case study on bulk carrier's accident contributors. Ocean Eng 208:107197. https://doi.org/10.1016/j.oceaneng.2020.107197

Nikas A, Doukas H (2016) Developing Robust Climate Policies: A Fuzzy Cognitive Map Approach. In: International Series in Operations Research and Management Science. pp 239–263

Nilsson R (2007) "What are your intentions?" - On Understanding Ship Bridge Decision Making. Chalmers University Of Technology

Norros L (2004) Acting under uncertainty. The core-task analysis in ecological study of work. VTT Technical Research Centre of Finland, Espoo

Obiedat M (1994) Lincoln University Digital Thesis Robust Semi-Quantitative Fuzzy Cognitive Map Model for Complex Systems and Case Study : Mitigating the Water Scarcity Problem in

Olazabal M, Neumann MB, Foudi S, Chiabai A (2018) Transparency and Reproducibility in Participatory Systems Modelling: the Case of Fuzzy Cognitive Mapping. Syst Res Behav Sci 35:791–810. https://doi.org/10.1002/sres.2519

Orlandi L, Brooks B (2018) Measuring mental workload and physiological reactions in marine pilots: Building bridges towards redlines of performance. Appl Ergon 69:74–92. https://doi.org/10.1016/j.apergo.2018.01.005

Øvergård KI, Bjørkli CA, Røed BK, Hoff T (2010) Control strategies used by experienced marine navigators: Observation of verbal conversations during navigation training. Cogn Technol Work 12:163–179. https://doi.org/10.1007/s10111-009-0132-9

Øvergård KI, Sorensen LJ, Martinsen TJ, Nazir S (2014) Characteristics of Dynamic Positioning Operators' Situation Awareness and Decision Making during Critical Incidents in Maritime Operations. In: Ahram T, Karwowski W, Marek T (eds) Proceedings of the 5th International Conference on Applied Human Factors and Ergonomics AHFE 2014. Krakow

Øvergård KI, Sorensen LJ, Nazir S, Martinsen TJ (2015) Critical incidents during dynamic positioning: operators' situation awareness and decision-making in maritime operations. Theor Issues Ergon Sci 16:366–387. https://doi.org/10.1080/1463922X.2014.1001007

Özesmi U, Özesmi SL (2004) Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. Ecol Modell 176:43–64. https://doi.org/10.1016/j.ecolmodel.2003.10.027

Papageorgiou EI (2014) Fuzzy Cognitive Maps for Applied Sciences and Engineering. Springer Berlin Heidelberg, Berlin, Heidelberg

Papageorgiou EI, Papageorgiou, Konstantinos Dikopoulou Z, Mouhrir A (2018) A web-based tool for Fuzzy Cognitive Map modeling. Int Congr Environ Model Softw 73

Papageorgiou EI, Salmeron JL (2013) A Review of Fuzzy Cognitive Maps Research During the Last Decade. IEEE Trans Fuzzy Syst 21:66–79. https://doi.org/10.1109/TFUZZ.2012.2201727

Papageorgiou K (2021) AND DECISION-MAKING SUPPORT USING ADVANCED Supervising committee

Papageorgiou K, Singh PK, Papageorgiou E, et al (2019) Fuzzy Cognitive Map-Based Sustainable Socio-Economic Development Planning for Rural Communities. Sustainability 12:305. https://doi.org/10.3390/su12010305

Patriarca R, Bergström J (2017) Modelling complexity in everyday operations: functional resonance in maritime mooring at quay. Cogn Technol Work 19:711–729. https://doi.org/10.1007/s10111-017-0426-2

PERROW C (2011) Normal Accidents, REV-Revi. Princeton University Press

Pickup L, Lang A, Shipley L, et al (2019) Development of a Clinical Interface for a Novel Newborn Resuscitation Device: Human Factors Approach to Understanding Cognitive User Requirements. JMIR Hum Factors 6:1–13. https://doi.org/10.2196/12055

Porathe T, Prison J, Man Y (2014) Situation awareness in remote control centres for unmanned ships. In: Proceedings of Human Factors in Ship Design & Operation, 26-27 February 2014, London, UK. p 93

Pourzanjani M, Zheng P (2001) Human Reliability Assessment for Ship Encounters. Saf Reliab 21:21–30. https://doi.org/10.1080/09617353.2001.11690712

Prison J, Dahlman J, Lundh M (2013) Ship sense-striving for harmony in ship manoeuvring. WMU J Marit Aff 12:115–127. https://doi.org/10.1007/s13437-013-0038-5

Procee S, Borst C, Paasen R van, Mulder M (2017) Toward Functional Augmented Reality in Marine Navigation: A Cognitive Work Analysis. 16th Int Conf Comput IT Appl Marit Ind 298–312

Qiao W, Liu Y, Ma X, Liu Y (2020) Human Factors Analysis for Maritime Accidents Based on a Dynamic Fuzzy Bayesian Network. Risk Anal 40:957–980. https://doi.org/10.1111/risa.13444

Rønningen JV, Øvergård KI (2017) Shared pilot passage plan and navigational safety during pilotage. WMU J Marit Aff 16:439–454. https://doi.org/10.1007/s13437-017-0128-x

Rouse R (2022) Pilotage Technology - A look inside a Pilot’s technology toolkit. In: Navig. https://www.nautinst.org/resources-page/pilotage-technology-a-look-inside-a-pilot-s-technology-toolkit.html. Accessed 25 Sep 2022

Saaty, Thomas L., The Analytic Hierarchy Process, McGraw-Hill, 1981.

Saaty TL (1988) What is the Analytic Hierarchy Process? In: Mathematical Models for Decision Support. Springer Berlin Heidelberg, Berlin, Heidelberg, pp 109–121

Sánchez-Beaskoetxea J, Basterretxea-Iribar I, Sotés I, Machado M de las MM (2021) Human error in marine accidents: Is the crew normally to blame? Marit Transp Res 2:100016. https://doi.org/10.1016/j.martra.2021.100016

Sandhåland H, Oltedal H, Eid J (2015) Situation awareness in bridge operations – A study of collisions between attendant vessels and offshore facilities in the North Sea. Saf Sci 79:277–285. https://doi.org/10.1016/j.ssci.2015.06.021

Sharma A, Nazir S, Ernstsen J (2019) Situation awareness information requirements for maritime navigation: A goal directed task analysis. Saf Sci 120:745–752. https://doi.org/10.1016/j.ssci.2019.08.016

Shu Y, Daamen W, Ligteringen H, Hoogendoorn SP (2017) Influence of external conditions and vessel encounters on vessel behavior in ports and waterways using Automatic Identification System data. Ocean Eng 131:1–14. https://doi.org/10.1016/j.oceaneng.2016.12.027

Stanton NA, Salmon PM, Rafferty LA, et al (2017) Human Factors Methods, 2nd Editio. CRC Press, London

Stanton NA, Salmon PM, Rafferty LA, et al (2013) Human factors methods: A practical guide for engineering and design, 2nd edition, Second. Ashgate

The Maritime Executive (2023) First officer of vessel being overtaken is blamed for collision. In: The Maritime Executive. https://maritime-executive.com/article/first-officer-of-vessel-being-overtaken-is-blamed-for-collision. Accessed 20 Oct 2023

Tolman EC (1948) Cognitive maps in rats and men. Psychol Rev 55:189–208. https://doi.org/10.1037/h0061626

Tušl M, Rainieri G, Fraboni F, et al (2020) Helicopter Pilots' Tasks, Subjective Workload, and the Role of External Visual Cues During Shipboard Landing. J Cogn Eng Decis Mak 14:242–257. https://doi.org/10.1177/1555343420948720

Uǌurlu Ö, Yildirim U, Başar E (2015) Analysis of grounding accidents caused by human error. J Mar Sci Technol 23:748–760. https://doi.org/10.6119/JMST-015-0615-1

van Vliet M, Kok K, Veldkamp T (2010) Linking stakeholders and modellers in scenario studies: The use of Fuzzy Cognitive Maps as a communication and learning tool. Futures 42:1–14. https://doi.org/10.1016/j.futures.2009.08.005

van Westrenen F, Praetorius G (2012) Maritime traffic management: A need for central coordination? Cogn Technol Work 16:59–70. https://doi.org/10.1007/s10111-012-0244-5

Vantorre M, Eloot K, Delefortrie G, et al (2017) Maneuvering in Shallow and Confined Water. In: Encyclopedia of Maritime and Offshore Engineering. John Wiley & Sons, Ltd, Chichester, UK, pp 1–17

Wagenaar WA, Groeneweg J (1987) Accidents at sea: Multiple causes and impossible consequences. Int J Man Mach Stud 27:587–598. https://doi.org/10.1016/S0020-7373(87)80017-2

Wickens CD, Williams A, Clegg BA, Smith CAP (2020) Nautical Collision Avoidance. Hum Factors J Hum Factors Ergon Soc 62:1304–1321. https://doi.org/10.1177/0018720819871409

Wild CRJ (2011) The Paradigm and the Paradox of Perfect Pilotage. J Navig 64:183–191. https://doi.org/10.1017/S0373463310000366

Yoon BS, Jetter AJ (2016) Comparative analysis for Fuzzy Cognitive Mapping. In: 2016 Portland International Conference on Management of Engineering and Technology (PICMET). pp 1897–1908

Yuan Z-M, He S, Kellett P, et al (2015) Ship-to-Ship Interaction During Overtaking Operation in Shallow Water. J Sh Res 59:172–187. https://doi.org/10.5957/JOSR.59.3.150004

Yule S, Paterson-Brown S (2012) Surgeons' Non-technical Skills. Surg Clin North Am 92:37–50. https://doi.org/10.1016/j.suc.2011.11.004

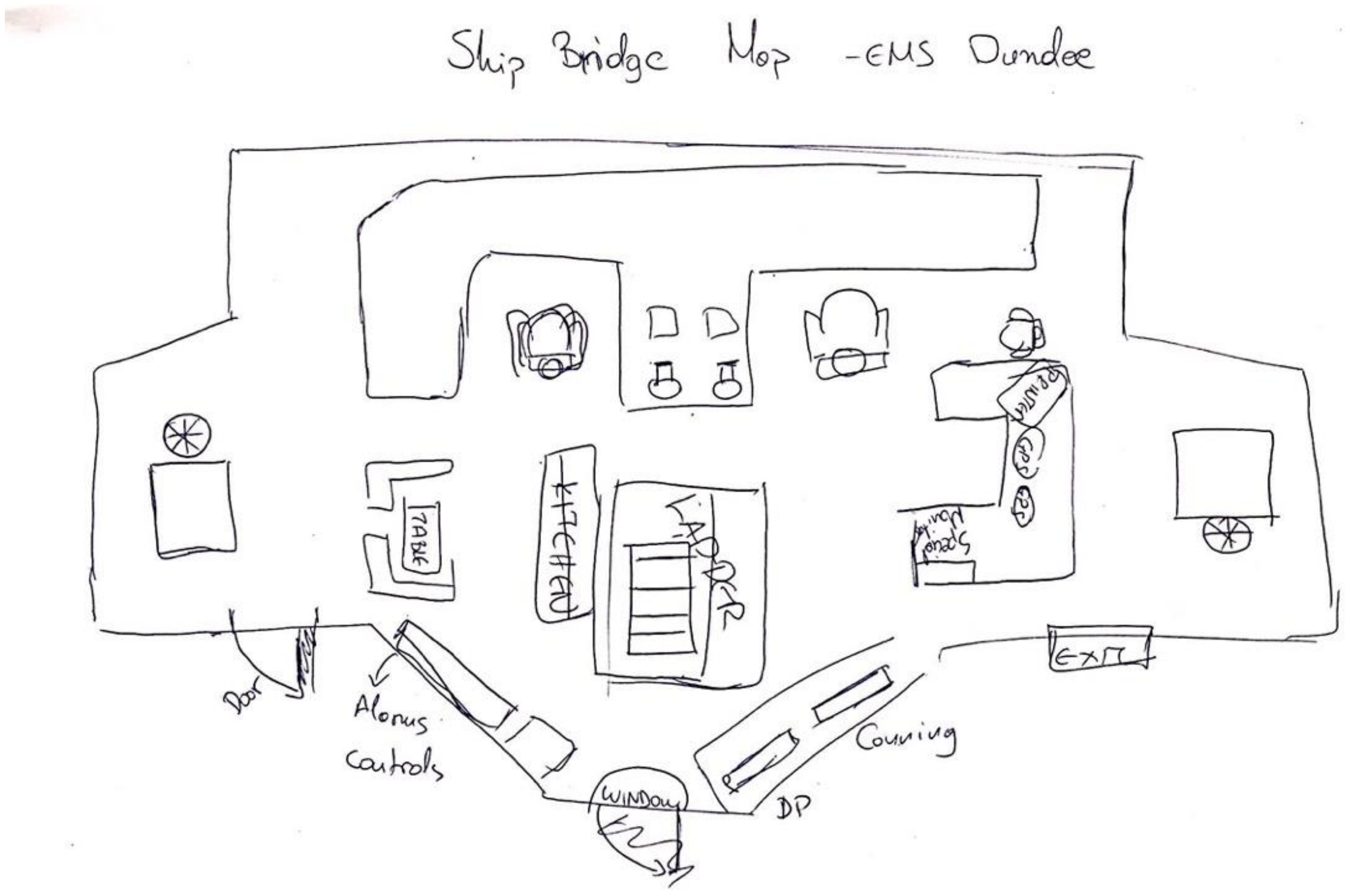
Zadeh LA (1965) Fuzzy sets. Inf Control 8:338–353. https://doi.org/10.1016/S0019-9958(65)90241-X

Zadeh LA (1986) A Simple View of the Dempster-Shafer Theory of Evidence and Its Implication for the Rule of Combination. AI Mag 7:85. https://doi.org/10.1609/aimag.v7i2.542

Zhou Y, Daamen W, Vellinga T, Hoogendoorn SP (2023) Ship behavior during encounters in ports and waterways based on AIS data: From theoretical definitions to empirical findings. Ocean Eng 272:113879. https://doi.org/10.1016/j.oceaneng.2023.113879

Appendices

APPENDIX A: The full activities analysis from the field trip.



Katelina (1/2)

"Activities Observations"

→ Slow manovr

DP - Docking Pilot
P - Petrikowski → fast manoevr
M - Master
OOW - Officer of Watch
FM - First Mate
TP - Trainee Pilot
PS - Pilot Station

Observer	
Informant(s) (if any)	Pilot - Petrikowski
Date	29.3.17
Start time:	13.30
Finish time:	20.30

Observation Record

Time	**Actor**	**Activities**
13.30	Docking 2 See Pilot	Pilot Cards
13.40	DP	Talk with VTS Report the status | Permission to use fairway
	DP	A vessel is in the fairway (asks why)
13.42	P	Setting up PPU
13.47	DP	Leaves the ship Advisory role
[illegible]	OOW / DP	Sees off the DP
4 14:03		
13:50	P	Takes over
14:00	M	Order to prepare ladder at 3 km for P
		Smooth trip

Katelina (2|2)

Time	**Actor**	**Activities**
14:55	M, P	Half an hour to reach pilot ship
		Meeting point is set on PPU (Pilotff. Wangeroog
15:20	TP - PS	Call that we are on our way to Pilot T. (30' work)
15:30		Preparing for change
		Alarm that weare off the safe passage area
		↳ AIS accuracy

EMS Dundee

Time	Actor	Activities
16:00		On board | Procedures were kept, we were welcomed
16:10	TP	Contact with Weser Pilot station
17:20	M, P, TP	Autopilot on - TIDE M leaves bridge, one crew member stays
17:35		Meal from ship
18:35	P, TP	Fairway gets narrower 300 - 220m
18:40		Increase of traffic
18:45		Is there enough space or not? ~~Check~~ fairway status
		a dunger will go to a dunking area, solved problem of giving fairway
		Overtaking in progress
19:00		Overtaking complete SOG 7.3
19:15	1	Discussion on high tidal influence
~~19:30~~		+ side current
19:30		Very limited visibility
19:40		Reached Bremerhaven
19:49		SOG 8.3 kn

19:56 Preparation to disembarge

Tools and Technologies

Tool/Technologies	Description, Uses, Notes
ECDIS	Planning & Navigation
PPU	Only more info for Pilot (ie bathymeter)
Radar	

APPENDIX B: Procedure of ACTA

Goal: to extract the cognitive demands associated with a specific task and scenario
5-6 interviewees, SMEs from pilot association in Bremerhaven.
Materials: Flipcharts/ A4, A3 blank pages / whiteboard, pens, markers, a chart and ships from cardboard for the simulation interview
Equipment: Video camera, audio recorder, photo-camera
Selection of SMEs by the corresponding person on site (Captain Marc Petrikowski)

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3 main parts:

- Task diagram
- Knowledge Audit
- Simulation Interview

1.1 Introduction (10 min): The research purpose, the concept of ACTA and how the data collection will be performed (stages, what data is collected, how the data will be used)

- Intro about myself
- Welcome to the meeting today. We are going to have a guided discussion as part of a multi study investigation of the critical elements that affect pilots and the ship bridge team develop and maintain situation awareness while navigating in confined waters.
- Our discussion today is based on a methodology called CTA that is used to elicit and represent in a systematic way knowledge and information about the thought processes you deploy while making decisions for the task. The results of the analysis can inform designers on how the displays and sensors of the ship bridge may provide cognitive support to the pilot and crew. The outcome of what we do today is information about why each task element is often found to be difficult, identification of common pitfalls/errors incurred by novices, and cues and strategies that experts use to overcome the difficulties.

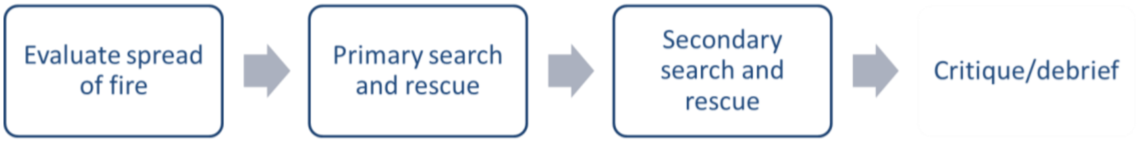
1.2 Consent Forms

2.1. TASK DIAGRAM (TASK IS OVERTAKING IN RESTRICTED FAIRWAY OF OUTER WESER)

The purpose of the task diagram is to elicit a broad overview of the task under analysis in order to focus the knowledge audit and simulation interview parts of the analysis. The diagram serves as a road map for next interview parts and provides an overview of the major steps involved in the task and the sequence in which the steps are carried out

Prompt question:

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?"
Please encircle the Task steps that require cognitive skills (judgements, assessments, problem solving, thinking skills) – where you need to think hard and make complex decisions
Show example of Fireground command that attend to a burning building.



2.2. KNOWLEDGE AUDIT

To highlight instances in the task under analysis what expertise from the pilot is required and where.
Use of the following basic probes

i) **Past & Future.** Experts can figure out how a situation developed, and they can think into the future to see where the situation is going. Among other things, this can allow experts to head off problems before they develop.

- *Is there a time when you walked into the middle of a situation and knew exactly how things got there and where they were headed?*

(follow up)

- *In this situation, how would you know this? What cues and strategies are you relying on?*
- *In what way would this be difficult for a less experienced person? What makes it hard to do?*

j) **Big Picture.** Novices may only see bits and pieces. Experts are able to quickly build an understanding of the whole situation—the Big Picture view. This allows the expert to think about how different elements fit together and affect each other.

- *Can you give me an example of what is important about the Big Picture for this task?*
- *What are the major elements you have to know and keep track of?*

k) **Noticing.** Experts are able to detect cues and see meaningful patterns that less-experienced personnel may miss altogether. I know this happens all the time, but my guess is that the more experience you have, the more accurate your seemingly unusual judgments become.

- *Have you had experiences where part of a situation just "popped" out at you; where you noticed things going on that others didn't catch? What is an example? What cues and strategies are you relying on? Were you right? Why (or why not)?*
- *Have you ever detected the wrong pattern, because of a false cue? Cues that are very similar, but lead to different situations?*

- *In what way would this be difficult for a less experienced person? What makes it hard to do?*

l) **Job Smarts**. Experts learn how to combine procedures and work the task in the most efficient way possible. In seafaring, it is important not to waste time and resources and navigate with safety.

- *When you do this task, are there ways of working smart or accomplishing more with less—that you have found especially useful? "How does this differ from what you did as a trainee pilot?"*

m) **Opportunities/Improvising.** Experts are comfortable improvising—seeing what will work in this particular situation; they are able to shift directions to take advantage of opportunities.

- *Can you think of an example when you have improvised in this task or noticed an opportunity to do something better?*

n) **Self-Monitoring.** Experts are aware of their performance; they check how they are doing and make adjustments. Experts notice when their performance is not what it should be (this could be due to stress, fatigue, high workload, etc.) and are able to adjust so that the job gets done.

- *Can you think of a time when you realized that you would need to change the way you were performing in order to get the job done?*

o) **Anomalies.** Novices don't know what is typical, so they have a hard time identifying what is atypical. Experts can quickly spot unusual events and detect deviations. And, they are able to notice when something that ought to happen, doesn't.

- *Can you describe an instance when you spotted a deviation from the norm, or knew something was amiss during a pilotage activity?*

p) **Equipment Difficulties**. Equipment can sometimes mislead. Novices usually believe whatever the equipment tells them; they don't know when to be skeptical.

- *Have there been times when the equipment (PPU, AIS, Radar, ECDIS) pointed in one direction, but your own judgment told you to do something else? Or when you had to rely on experience to avoid being led astray by the equipment?*

-------------10 MIN BREAK--------------
(preparation of the room for the next interview phase)

2.3. SIMULATION INTERVIEW

The simulation interview will be realized as a half interactive mid fidelity simulation adapting the technique used by (Brödje et al, 2010). The scenario used is based on elements from investigation reports, which include real events, conditions and other situation characteristics. The scenario recreates a typical everyday overtaking activity in outer Weser with an unpredictable event taking place and has been created with the help of an active pilot from the Bremerhaven station. Field trip data and initial interviews have also provided enriching material. The scene is created by capturing the status of the fairway on 19.7.2017 using the openseamap project and includes only sea marks and marine traffic information. The scene will be printed and lay on a table. Thin plastic sheets will be placed on the map and non-permanent markers will be used to mark the initial and end positions of the ships, as well as the courses of all the ships involved in the setting.

Scenario:

- You are the pilot on the **MAERSK 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 **OTTAWA EXPRESS** is outbound.
- Weather: T: 18-19^{o}C, wind at 17Km/h (3Bft) SW, gusts at 33Km/h(5Bft), visibility 15km, cloudy
- High tide 3.37m at 10:52 AM, Low tide 0.5m at 5:25 PM
- Current: 3.3 knots on the surface and 2.5 knots at a depth of 2m below mean low water level

Time is 12:00
Please walk me through the process of overtaking?
What are possible important events that might occur during your shift? What can cause trouble?
Major events that I can ask the pilots if they don't mention them

- Course alteration of the overtaken ship (incident on 18.7)
- Very strong unpredicted wind from southern direction (8-9Bf)
- Fog patches that form suddenly and reduce visibility
- Engine failure in the ship being overtaken

Pilots are asked to verbally walk the interviewer through the process and identify any important aspects of the task and the critical cues used in their decision process.
FOR EACH MAJOR EVENT, elicit the following information:

- What do you think is going on here? What is your assessment of the situation at this point in time?

- As the pilot that advices the master in this scenario, what actions, if any, would you take at this point in time?[3]

- What pieces of information led you to this situation assessment and these actions?

    - What does this information/element mean to you? It helps you be aware of what?
    - Do you consider this information in relation to other elements or conditions?

- What sensors/instruments do you use to gather the necessary information?

- In what ways can the decision be difficult? What errors would an inexperienced person be likely to make in this situation?

Gather keywords in a simulation interview table. Film the simulation interview and analyze it later
END of interview: Give the gift and the demographic data sheet

EXAMPLE (from a study with firefighters that face an explosion and a burning building)

EVENTS	ACTIONS	ASSESSMENT	CRITICAL CUES	POTENTIAL ERRORS
ON-SCENE ARRIVAL	Account for people (names) Ask neighbours (but don't take their word for it, check it out yourself) Must knock on or knock down to make sure people aren't there	It's a cold night, need to find place for people who have been evacuated	Night time Cold -> 15° Dead space Add on floor Poor materials wood (punk board), metal girders (buckle and break under fire) Common attic in whole building	Not keeping track of people (could be looking for people who are not there)
INITIAL ATTACK	Watch for signs of building collapse If signs of building collapse, evacuate and throw water on it from outside	Faulty construction, building may collapse	Signs of building collapse include: What walls are doing: cracking What floors are doing: groaning What metal girders are doing: clicking, popping Cable in old buildings hold walls together	Ventilating the attic, this draws the fire up and spreads it through the pipes and electrical system

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APPENDIX C: Vessel data

Name	**OTTAWA EXPRESS**
Category	Cargo vessels
Vessel Type	Container ship
Attributes	
Service Status	in service
IMO	9165360
ENI	---
Length	245 m
Width	32 m
Height	16.0 m
Year Built	1998
Builder	Daewoo Heavy Industries Ltd.
Hull Description	Type: 330 - Container Ship Vessel shape: Monohull ship 1A1 ICE-1A Container Carrier E0 NAV-O TMON Max. draught: 10,78 m Yard / Hull number: 4057
Year Scrapped	---

Capacities Tonnage and cargo facilities

Dead Weight	**40,882 t**
Gross Tonnage	39174
Container Capacity	2,808 TEU
14mt Container Capacity	2,010 TEU
Reefer Container Capacity	248 TEU
Person Capacity	---
Cargo Capacity	Ballast capacity: 15,672.2 m3 Max. 2808 (TEU) Max. 2010 14 tons (TEU) Reefer 248 (TEU)

Gear	Anchor Chain: Length: 660 Diameter: 78 Material Quality: K3

Engine

Engine Description	Engine: 34.580 PS; Gears: fest; Propeller: 1 rechts; Bow thruster: 1.680 kW; Stern thruster: no; Rudder: 1 Blades semi-spade; Auxiliary boiler, vertical shell type 2 Mission OS Aalborg Industries A/S Auxiliary boiler, composite 1 AQ-16 Alfa Laval Aalborg A/S Emergency generator diesel engine Diesel engine NOT SET Intermediate shaft Shaft Main generator diesel engine AI 8L28/32H MAN B&W Diesel AG Main generator diesel engine AO 8L28/32H MAN B&W Diesel AG Main generator diesel engine F 8L28/32H MAN B&W Diesel AG Manoeuvring thruster electric power unit Electric power unit Manoeuvring thruster, tunnel LIPS CT 225 NOT SET Propeller shaft arrangement Propeller, mono-block Propeller, mono-block Hyundai Heavy Ind. Co. Ltd. Propulsion diesel engine 7L80MC MAN B&W Diesel A/S Max. speed: 21,00 Kn
Design Max. Speed	21.0 kn

Name	**MAERSK GUAYAQUIL**
Category	Cargo vessels
Vessel Type	Container ship
Attributes	
Service Status	in service
IMO	9727871
ENI	---
Length	337 m
Width	48 m
Height	---
Year Built	2015
Builder	JIANGSU YANGZI XINFU SHIPBUILDING - JINGJIANG, CHINA

Hull Description	---
Year Scrapped	---

Capacities Tonnage and cargo facilities

Dead Weight	**119,359 t**
Gross Tonnage	113042
Container Capacity	10,000 TEU
14mt Container Capacity	---
Reefer Container Capacity	---
Person Capacity	---
Cargo Capacity	---
Gear	---

Engine

Engine Description	---
Design Max. Speed	---

MARINO

- Type Cargo ship - Flag Germany
- IMO ---
- MMSI 211483560
- Callsign DA2518
- Year Built ---
- Length 80 m
- Width 10 m
- Draught Avg 1.4 m / ...
- Speed Avg/Max 6.6 kn / 11.8 kn
- Deadweight ---
- Gross Tonnage ---

APPENDIX D: Knowledge Audit Results

Probe	Response
Past, Present and Future	1. “I was on a smaller vessel and much faster and I had this nearly incident that I was coming very close to the other vessel because he was taking all the water from the river and since that time I really think twice before.”
	2. «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’.»
	3. **“you can try it, but you have to keep it in mind due to slack water we'll take much longer than you think.”** “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.”
	4. “He had to overtake again but on a narrow place here just close to the container terminal and because he needs to wait , he needs to skip a little bit the time, and I have to pass as well, because I cannot reduce because I have the order time for the Geeste.”
	5. “the vessel ahead of me, (that) we should be overtaking, was on the side of the fairway and suddenly I don't know what happened there, more and more to the port, this means she came more and more to the middle of the fairway.”
	6. “the situation in front of Bremerhaven container terminal was that some outbound traffic came to the situation. And he had no chance to go close to the pier and there is his mistake I am now approaching and then I got this vessel ahead of me and he has no chance to go anywhere and so he is blocking my way”
	7. “I am on board on a car carrier outbound with harbor pilots from the local river and we had a situation, an inbound big draft container vessel and she came in the river and the river pilots wanna leave the tugs and they wanna leave the vessel and I said no you stay here with tugs then we have the car carrier under control, I don't overtake cause first I wanna have seen this big container vessel turned to go with the right side to the container terminal. Cause that needs time and without tugs in the river with this strong wind condition I can go nowhere cause the river is blocked by these big container vessels and I can't control the car carrier without tugs to keep my position The problem was they didn't check the time need until the vessel is turned and there was also some other outbound vessel for which the inbound vessel were waiting and I saw clear container vessel will let pass the other vessel outbound and I am number two to pass the container vessel but after this they are gonna start turning and that was my point that I need the tugs longer as usual cause I can't pass a second vessel.”
Big Picture	1. «If you talk sometimes there's smaller communication on the bridge or the captain wants to speak with you and you cannot take so much attention to the VHF and this would be more difficult for inexperienced»

	2. «But here on the river is not the same due to the seabed of the river, it's changing the speed, the interaction of both ships is the difference in time of overtaking that you have to keep in mind as well.
	3. “You have to see your own position, the position of the other ship, your speed and the speed of the other ship. This is a major thing that you have to look on. The interaction of the ships of course. These are the major things, what you have to count on.”
	4. “You have to keep everything under control, you have to observe everything on the parallel part, you have to see the speed, the ship, the position and the interaction, you can't only have a look on the GPS where you go, what is your speed and the speed of the opponent you have to see as well what is the ship doing.”
	5. “the human factor played a big role actually otherwise all these currents we have to calculate as we spoke already about these dynamical actions, everything, if you don't have so much space for the overtaking but you have to”
	6. “If you're just looking ahead already “aha, there's one inbound vessel”, then ready the alarm your head already “ah”, then I have to think about that, so now let’s calculate, I'm so fast, this vessel let's say will maintain the speed, the other one is coming inbound so could I pass or not, should I stay behind?”
	7. “I am of course informed about the traffic, about the vessels underway. One of the big points which size vessels are going where in 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.”
Noticing	1. “this action was in the part where the 220m part opened to the 300m part. It started to overtake me and was okay at first, then we have a course change with this part, done this course change and just in this moment when he overtook me he didn't realize he has to do this course change and I didn't know whether it was written or not. We came very close”
	2. “these leisure crafts for example, you don't have them on the radar, they have no signal, they should not go in the middle, they should go at the side of the river”
	3. **“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**… First he was on 11 or 12 knots, I don't know exactly but later on he's always when I was increasing to 13 or 14 he had the same speed all of his own, it was clear there was some suction and he didn't realize, so I realized because I was aware... I'm always aware due to my first experience.”
	4. “if you are still on autopilot, or manual doesn't matter, if the helmsman try to keep the course and you see already the interaction of the rudder if he's always going to one side and trying to keep the course and he's always on port five or ten or something then you know already that there's a major interaction of the ship. This you have to observe as well.”
	5. “you give the proper commands to the helmsman and the helmsman just puts the rudder on the wrong side, or he's keeping the wrong course, or he's not steering exact enough.”

	6.	“the heading was wrong because then you're just heading on the red buoy line and you see just the red buoys there and nothing is correct, the heading is wrong, everything is wrong and you just think “what was wrong?”.
	7.	“Everything was fine, everything was going smooth and then suddenly, tsak, the vessel went to the port. Why? Couldn't be like this you know, just proceed. Proceed on the right side of the fairway, as usual. No, something happened,”
	8.	“the distance is going less and less so this is a critical point”
	9.	“I didn't calculate the other vessel could come from the old Weser, this is also part of the Weser, you know.”
	10.	“And we're coming closer and closer, she's going faster and faster… I'm staying on the middle of the fairway just because I would like to overtake this bigger one. And she's going more and more to the middle. I called him, “what's going on”, “oh sorry I forgot to inform you I'm the first, so don't go full ahead, you have to stay behind’ ”
	11.	“The weather conditions gave me the information by binocular, that looks like moving vessels”
	12.	“when I don't have a good clear english conversation I don't trust this other vessel. So I get doubt about overtaking and I will not do.”
	13.	“the fast container feeler vessel overtakes a car carrier proceeds with 7-8 kn more speed and then of course he has to stop in front of the container pier. And before this colleague thought *Oh, there is speed enough, I overtake* so I am good clear ahead of him but the situation in front of Bremerhaven container terminal was that some outbound traffic came to the situation. And he had no chance to go close to the pier and there is his mistake I am now approaching and then I got this vessel ahead of me and he has no chance to go anywhere”
Job smarts	**1.**	**“when you start your pilotage, the first maneuvers I always observe the helmsman, if he's looking good, this is also part of the bridge team.”**
	2.	«you know there is an effect but to keep it as low as possible, you try to keep it as short as possible that's why you overtake usually with a quite good speed. You don't do it usually with two three knots.” “with your PPU is much easier to gain some information because you can organize your picture as you want.”
	3.	“the undercurrent there is helping there it could be against, okay, here I should stay a little bit, maybe I will stay behind”.
	4.	“I will stay behind and then if I have more space then you are starting to calculate really okay so, now I have a space if anything happens if anyhow I could go more to port or more to starboard because I have the space. This is very important here narrow channel, only 220 meters,”

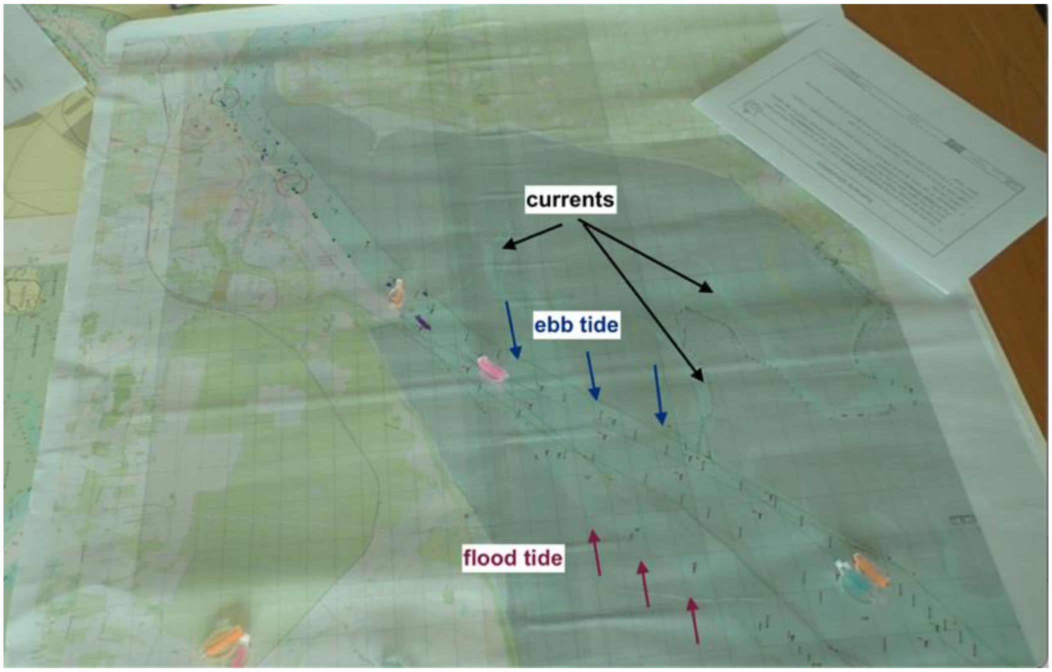
	5. “in the pre-planning, to say “okay, you have half an hour, I will overtake you from your port side, just notice this already, I'm coming from your stern”, I know, in half an hour some big vessel is coming, just overtake me on my port side of the fairway.” 6. “all vessels with pilot I get in contact 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.” 7. “I know the small draft of the vessel and I know the depths out of the river I go out of the river (fairway) and overtake this vessel but with this smart vessels or motor yachts it's always possible to overtake, you need no space, no big space, I don't effect opposite traffic cause the wideness of the river is full enough”
Opportunities & Improvising	1. “I try to give always enough way, this is very important. You have not so many alternatives anymore if the maneuver's started or if you are in the middle of the maneuver, you don't have so many options” **2. “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’ ”** 3. “You are relying usually on one source, not on different. You are not looking on the radar, then going to the GPS, the difference of current is good or something and you are rectifying this one, this one, this one and then you don't do this one. You are looking on your speed, their speed and you are looking on the ship. And the helmsman on the rudder and these are usually three four five things which is taking a lot of place then in this situation, during the situation and you are not relying on everything but on primar information input.” “if you do not come too much on the radar for example, when it is not the best, you are losing quite a lot of information as well because if you have sailing boats,which are not sailing with AIS or some drifting buoys or something you cannot take account on because you do not see so good on the screen but without you are lost as well. You have to check both, if the weather permits you have to look as well out of the window and say ‘okay, now according to the equipment I am on the radar line but I am not on the radar line, I am few meters out’ or they have the sailing boat which is not on the screen but obviously it is there, you have to observe your surrounding as well.” 4. “Now I know really size of the vessel, how she's reacting, how it all could be affected and then I say okay, it's not a problem, we are going with a full ahead, faster.” 5. “Could be really helpful sometimes just to call him, even if there is some call from me. Tell him “come on now we're not taking care of the situation, would you please go a little bit to starboard just to let me go”, something like that, or “could you reduce the speed”, like that.” 6. “he didn’t start to move to the right side and I came too hard in the center of the fairway and I had opposite traffic, and before I saw it, this smaller vessel, this captain ‘we are not go hard

		enough to starboard' it was just a negative point, but then I thought ok, the opposite traffic is not large vessels, at least I can go in the middle of the fairway"
Self-monitoring	1.	"when I was younger I was more affected by the opinion of the pilot"
	2.	"(As) a young pilot here I wasn't worried about anything. Meanwhile also other colleagues that are here for a longer time that "ah, it makes no sense to overtake due to or in relation to the danger".
	3.	"I'm really wondering when I have no visibility and I know there's traffic enough and big ships, I like to have another man by my side who is checking my action. But I don't only trust my PPU
	4.	**"I thought I could manage it without a tugboat and it was quite windy and I nearly had a damage, was like this. And the next time I was more or less in the same situation I was taking a tugboat for assisting."**
	5.	«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."
	6.	"You are relying usually on one source, not on different. You are not looking on the radar, then going to the GPS, the difference of current is good or something and you are rectifying this one, this one, this one and then you don't do this one. You are looking on your speed, their speed and you are looking on the ship. And the helmsman on the rudder and these are usually three four five things which is taking a lot of place then in this situation, during the situation and you are not relying on everything but on primar information input."
		"What I do is always to evaluate the voyage after each trip. I just have a short moment to say ah, this one and this one was not so good, I need to improve this, I could make this better, maybe the course line was not so good when the opponent was coming and passing or I could do this one and this one better."
	7.	"I see bigger vessel ahead of me, some inbound traffic, I talk from the beginning with the captain, till buoys 34 we even not calculate nothing, we will stay behind."
	8.	"say to yourself okay, I am coming let's say five minutes later but I will stay behind this vessel. She's going let's say more south than me, okay, just to find some way to go."
	9.	**"you must start early enough to slow the vessel to reach this speed for the tugs and sometimes in the beginning you have not the experience to do it early enough."**
		"you have a small vessel ahead with slow speed and you are one mile behind and you are doing 11 knots, so when you do a mathematic calculation and you say it needs time that you are past this vessel, so you are 8 miles ahead as one vessel is inbound with 16 - 18 knots. So in 30 minutes she is in front of you and in 30 min sometimes or calculation you have not overtaken this small vessel. You think 'Oh, I am very close' but that is not right cause this inbound vessel is in no time ahead of you and then you are wondering 'oh, so fast is this vessel'."

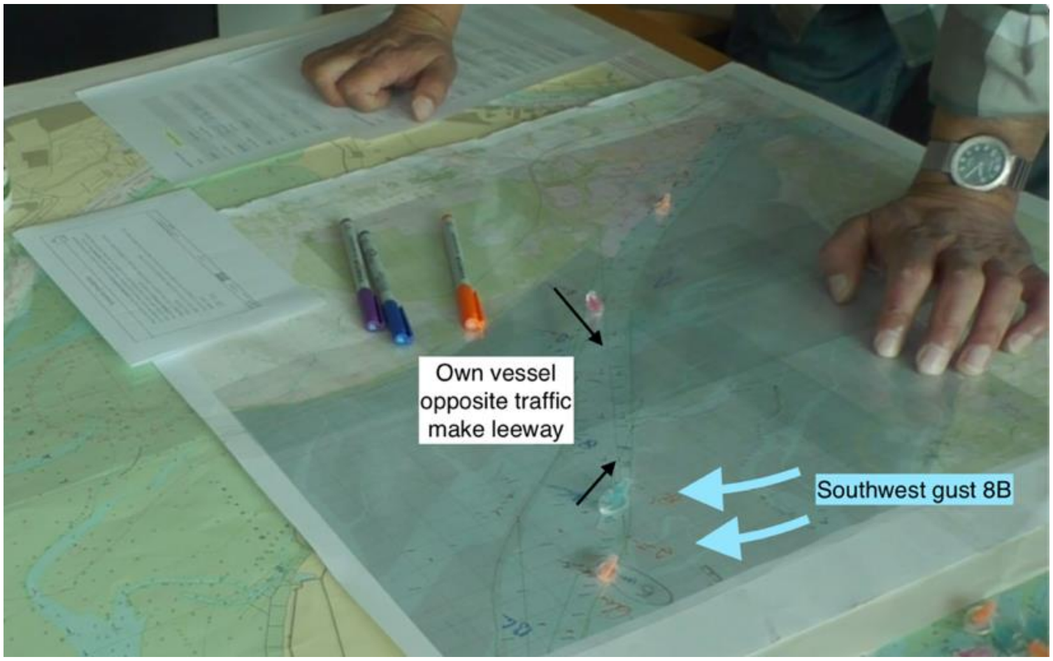
Anomalies	1.	“if I cannot get the speed which is in the pilot card for example, due to engine repair which they have had before board or I have a loading problem”
	2.	**“the vessels are not having the speed that they said before. For example a tanker said “We do 12kn” and in reality they do only 10.”**
	3.	“we try to overtake and due to the draft and the seabed, our speed was reducing so much that we're just passing with half a knot. From 3-4 knots it was dropping to half a knot so it takes long long time to overtake the other ship.
	4.	“I don't have the full speed of the bow thruster, I have only 80 percent maybe even less. So I made completely other maneuver and then I went smooth inside so it was okay,”
	5.	“I had the part of the river up to point where it gets wider … and the weather conditions were misty, not foggy, but misty, raining, drizzling, wintertime, 17.00 darkness starts and I overtook a vessel and before I checked a vessel more ahead and I thought this vessel was underway, but that was wrong that was a working dredgerAnd I stopped my overtaking cause I thought this is a lighted stern part of a vessel, the accommodation, but that was wrong. That was just a dredger, no movement, he was doing just 1-2 knots and working on the channel, I started to overtake and then i stopped-ceased maneuver.”
Equipment Difficulties	1.	“sometimes I don't have the correct positions for the AIS antennas, the ships enter the wrong figures in the AIS system and then your position is not there, maybe there. Might be a point when you're overtaking a vessel, ten twenty thirty meters,”
	2.	“the gyro sometimes are not really exact and the zero line of the radar is not exact, that is very important if you go on reduced visibility and you have to use the radar. And when the central line of the radar is not exactly the central line of the ship you can have big trouble sometimes”
	3.	“the central line of the radar was not the central line of the ship, she was showing about five degrees to starboard”
	4.	“the heading was wrong because then you're just heading on the red buoy line and you see just the red buoys there and nothing is correct, the heading is wrong,”
		“there are many types of different equipment which is not easy to handle or there is no real standard of operating the equipment, it is a really big problem because I think this is also a reason why we have our PPUs.”
	5.	**“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.”**

	6. “The radar picture was not clear so the target were not clear cause it was ‘catalogued’ like rain cloves on a picture and with modern radar machines the picture would be more clear, unlike these old machines.”

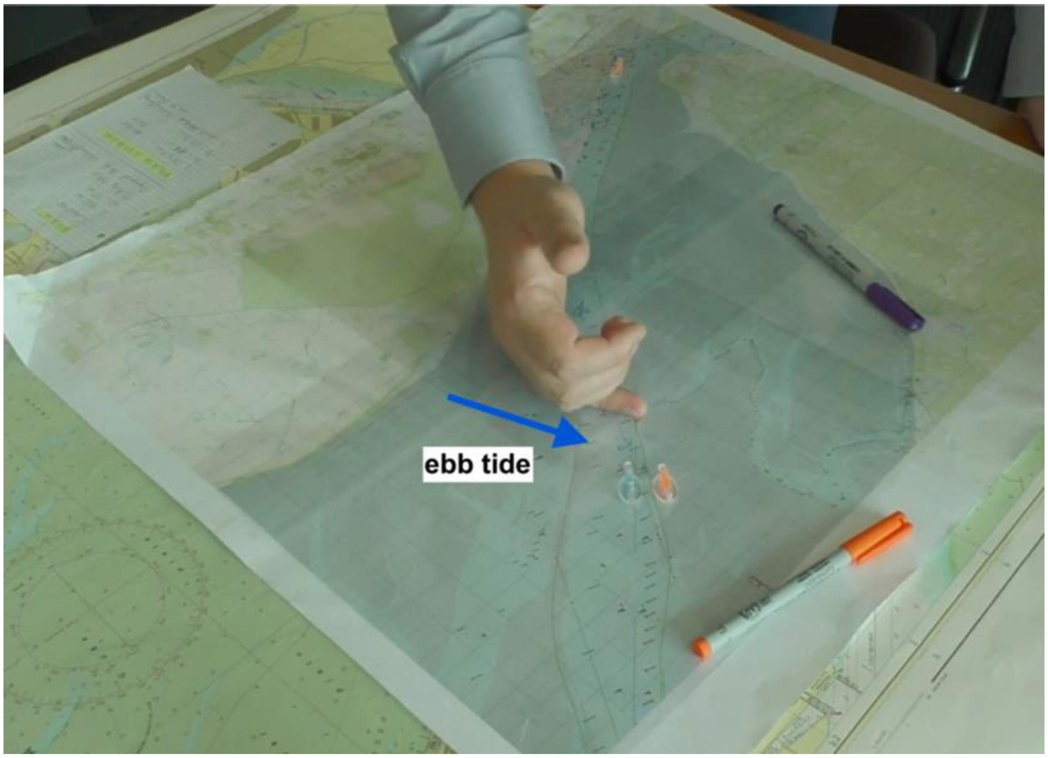
APPENDIX E: **Simulation Interview walkthroughs content analysis**



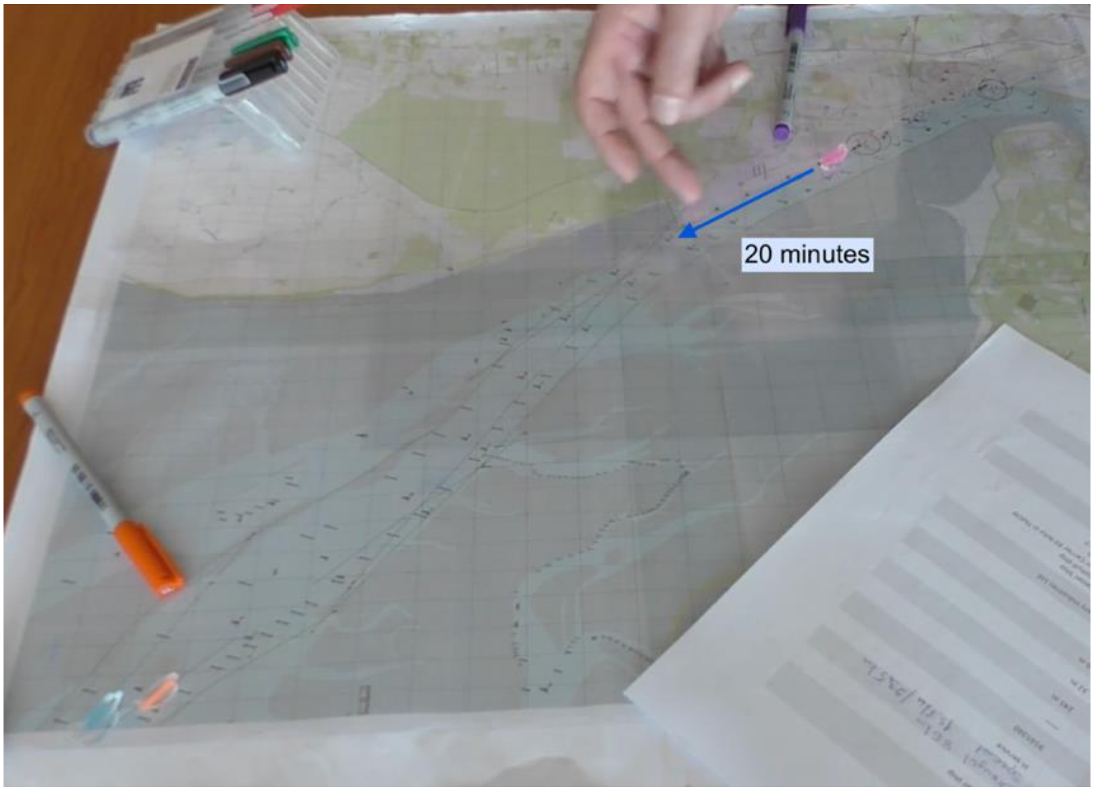
Appendix Figure 1 Participant 1 during the Simulation Interview



Appendix Figure 2 Participant 2 during the Simulation Interview



Appendix Figure 3 Participant 4 during the Simulation Interview



Appendix Figure 4 Participant 5 during the Simulation Interview

APPENDIX F: GUIDELINES FOR APPLYING COGNITIVE MAPPING METHODOLOGY

PART A. Task Analysis + Scenario walkthrough (30-40 min)

Step1: Define the Task under Analysis
Select and find the task or scenario under analysis, this is dependent upon the nature and the focus of the analysis

Step2: Task/Scenario observation
In order to prepare for the data collection phase, it is recommended that the analyst(s) involved observe the task or scenario under analysis. If an observation is not possible, a walkthrough of the task may suffice. This allows the analyst to fully understand the task and the participants' role during task performance.

Step3: Select appropriate participants
Once the task or scenario under analysis is defined, the analyst(s) should proceed to identify **at least 5 SMEs**. Typically, experienced users or decision makers within the system under study are used.

Step4: Develop the Task Diagram
Create an overview of the task under analysis, where the component task steps/subtasks and the steps that require the most cognitive skill are represented.
First the task is broken down to 3-6 steps/subtasks. A step is determined by the points where the mariner has to make a decision. Every time, the mariner identifies high level cognitive demands for the subtasks (ie situation awareness).

Step5: Scenario simulation
Setup with chart and plastic ships. Scenario is prepared with the help of a SME that is not a participant interview. Present each interviewee with the scenario information. First, the participant gives an overview of the task under analysis. Each event/ task step should be probed for SA requirements, actions, critical cues, errors and surrounding events.

- Action at each point in time
- What information elements lead you assess the situation

PART B. Cognitive Modeling (60 - 90 min)

The process of model construction consists of several stages:

1. First, experts **generate and select key concepts/factors** that are important influences on, or parts of, the system of interest. Factors can be from any domain (social, economic, physical, etc.) and may be qualitative or quantifiable.
2. Second, causal influences—**positive or negative links**—between factors are discussed and decided on, which allows for construction of a directed graph.

3. Finally, participants **rank** and **verbally describe** the strengths of these influences between factors, ultimately producing a directed graph with weighted links, which we refer to as the cognitive map or FCM

Each participant creates one FCM.

PREPARATION BEFORE MEETING

MATERIALS:

1. A4 pages (at least 5 blank pages in front of each participant + a pencil and a pen,
2. A pack of post it notes
3. Markers/pens
4. A map of the area that the scenario will take place
5. Models of the ships
6. Ship characteristics
7. The Use Cases information
8. Mental modeler software
9. a printed copy of the example cognitive mapping (METT-TC factors)
10. the cognitive mapping protocol (present text)
11. A printed page with the Likert 5 grade scale.
12. Online/Printed forms for the socio-economic data of the participant (to be filled by each participant at the **END of the meeting**)
13. please read carefully also the GUIDELINES II

In case you prefer using your computer to show the relevant material to respondents be sure that you have with you in your computer the above mentioned files. It would be nice if we could include in our final report at least one photo of an interview from each participant/group.

PROCEDURE

1. Meeting the participant, small talk etc.

2. Introducing the subject:

   Today we will hold a participatory modeling workshop. Our aim is to find out what are your views/perceptions about the factors that affect your decision-making strategies during performing safe overtaking in outer Weser while being part of the ship bridge team. Together, we will:

- identify your reasoning mechanisms and knowledge in a form that other stakeholders and interface designers will be able to perceive them and

- determine the critical information for each step of a navigational goal as the goal implementation progresses.

  I have prepared a scenario in cooperation with Captain Marc Petrikowski that will be used today to facilitate the discussion.

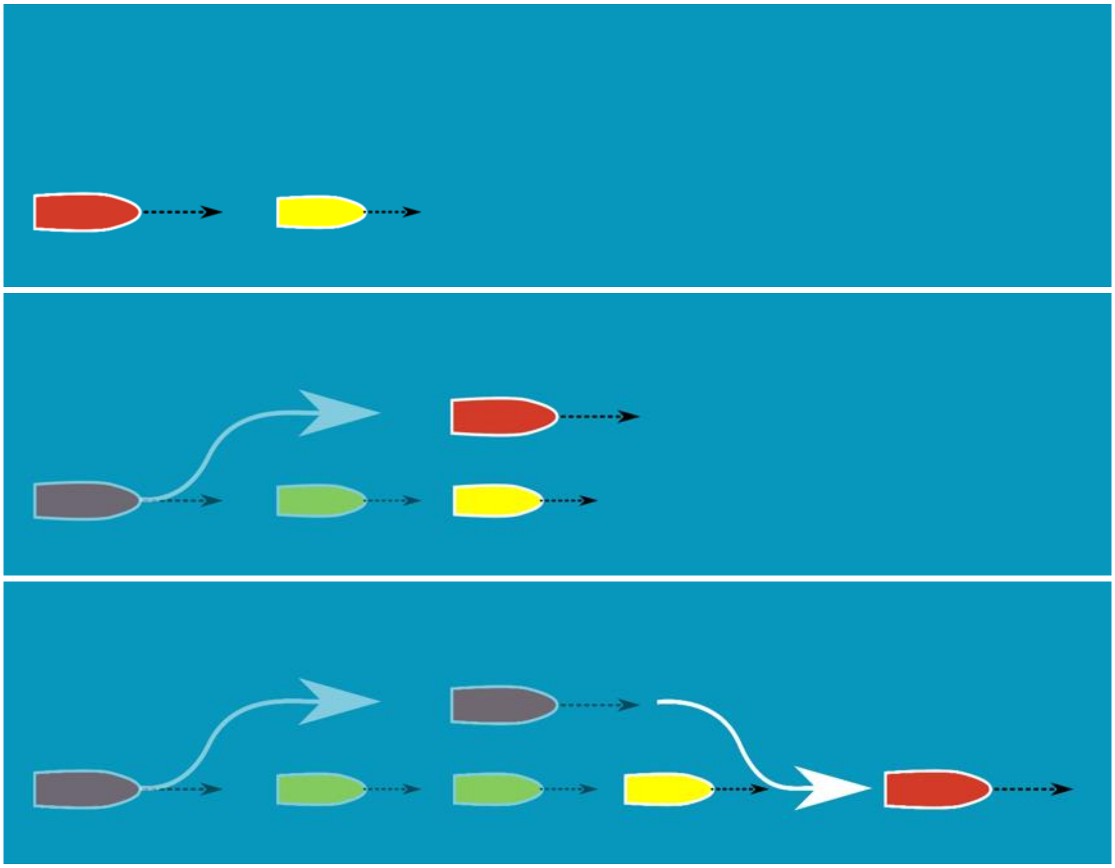
  During our discussion I would like you to remember that there are no wrong or right answers, there are simply different opinions, which we encourage you to express freely.

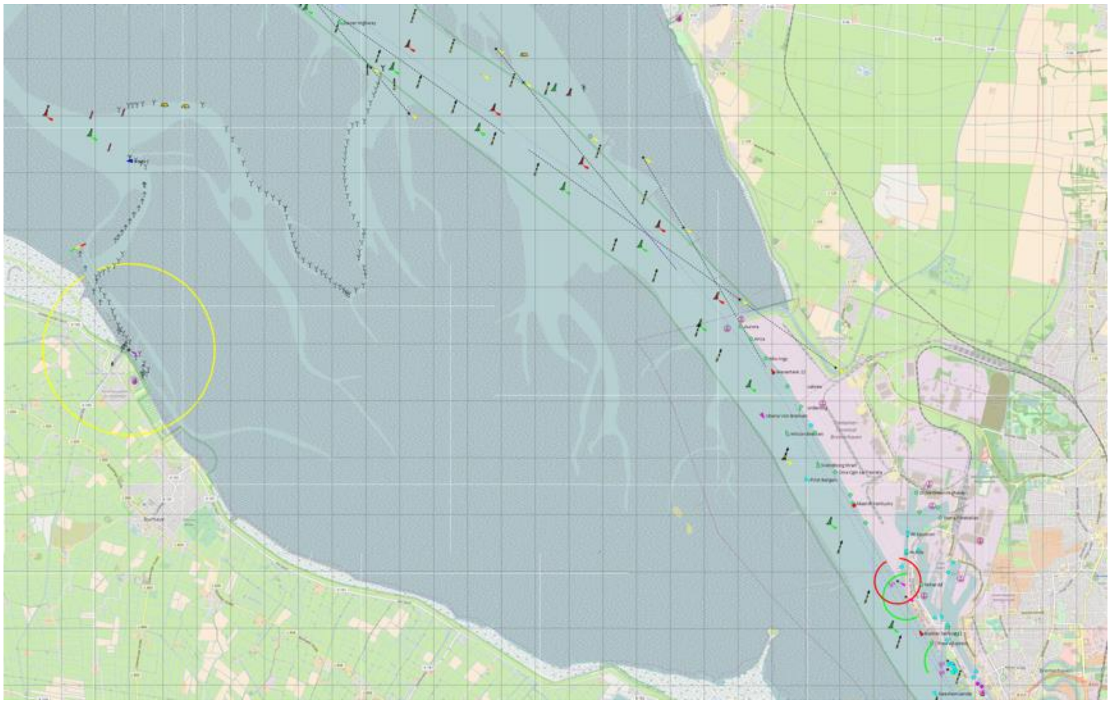
  SHOW the Scenario

  Use Case: Vessel A is overtaking vessel B in outer Weser

  MATERIAL: Map + markers + ship models + ship info

  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?

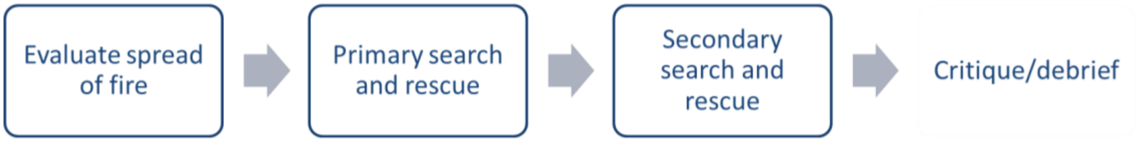




3. Proceed with the walkthrough of the task. Participants use the ship models and markers on the provided chart. Describe the actions you take to perform the maneuver.

4. Now I would like you to think of about what you do when you are making decisions in the scenario. Can you break this task into **less than 6 but more than 3 steps** or subtasks? Now could you tell me which of these steps have high level cognitive demands (ie situation awareness)
    a. Prompt for action at each point in time

Show example of Fireground command that attend to a burning building.



5. Scenario Simulation Interview

The simulation interview will be realized as a half interactive mid fidelity simulation adapting the technique used by (Brödje et al, 2010)[1]. The scenario used is based on elements from investigation reports, which include real events, conditions and other situation characteristics. The scenario recreates a typical everyday overtaking activity in outer Weser with an unpredictable event taking place and has been created with the help of an active pilot from the Bremerhaven station. Field trip data and initial interviews have also provided enriching material.

The scene is created by capturing the status of the fairway on 19.7.2017 using the openseamap project and includes only sea marks and marine traffic information. The scene will be printed and lay on a table. Thin plastic sheets will be placed on the map and non-permanent markers will be used to mark the initial and end positions of the ships, as well as the courses of all the ships involved in the setting.

Scenario:

- You are the pilot on the **MAERSK GUAYAQUIL** that has just left 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 **OTTAWA EXPRESS** is inbound.
- Weather: T: 18-19°C, wind at 17Km/h (3Bft) SW, gusts at 33Km/h(5Bft), visibility 15km, cloudy
- High tide 3.37m at 10:52 AM, Low tide 0.5m at 5:25 PM
- Current: 3.3 knots on the surface and 2.5 knots at a depth of 2m below mean low water level

Time is 12:00

Please walk me through the process of overtaking?

What are possible important events that might occur during your shift? What can cause trouble?

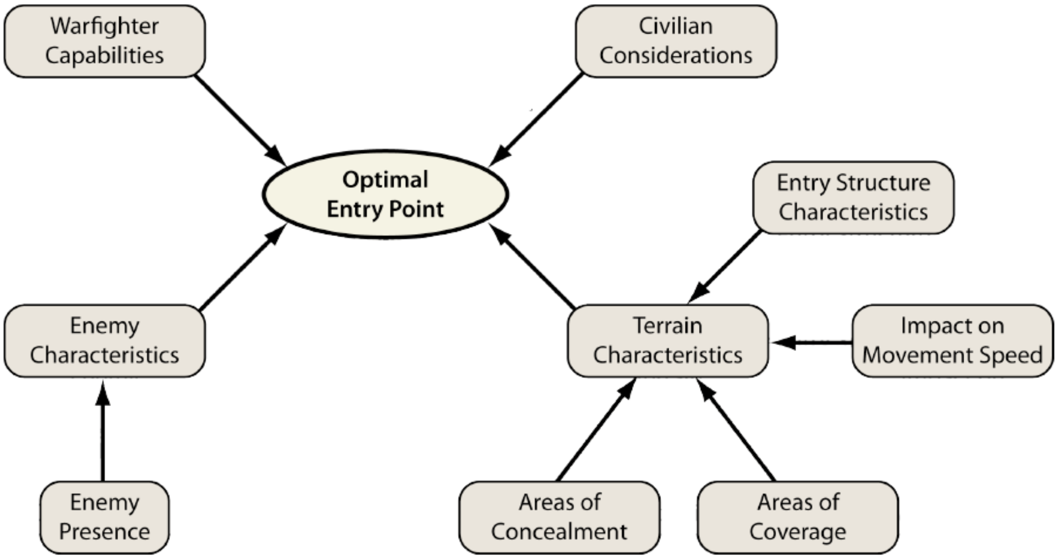
Major events that I can ask the pilots if they don't mention them

- Course alteration of the overtaken ship (incident on 18.7)
- Very strong unpredicted wind from southern direction (8-9Bf)
- Fog patches that form suddenly and reduce visibility
- Engine failure in the ship being overtaken
- Different ship types

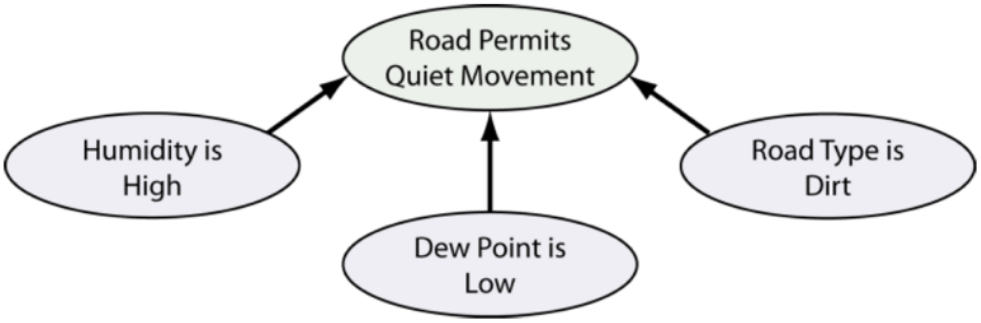
Pilots are asked to verbally walk the interviewer through the process and identify any important aspects of the task and the critical cues used in their decision process.

USE ACTA SIMULATION INTERVIEW PROMPTS

6. **SHOW THE FCM for MILITARY (10)**
   We will start with an example from the military. What we see here is the cognitive map of an infantry platoon leader.
   The expert mentions the militarily relevant aspects of the environment or background against which a military operation occurs known as Mission, Environment, Terrain and Weather, Troops, Time Available and Civil Considerations (METT-TC factors), the accurate depiction of which is necessary for good decision-making.



In order for this map to be constructed, the experts were asked to tell <u>how those factors are interrelated</u>, how each factor influences the other.
For **terrain considerations**, specifically understanding **areas of concealment**, an Army Infantry Platoon Leader may want to know the following factors: **humidity, type of road, and dew point**.

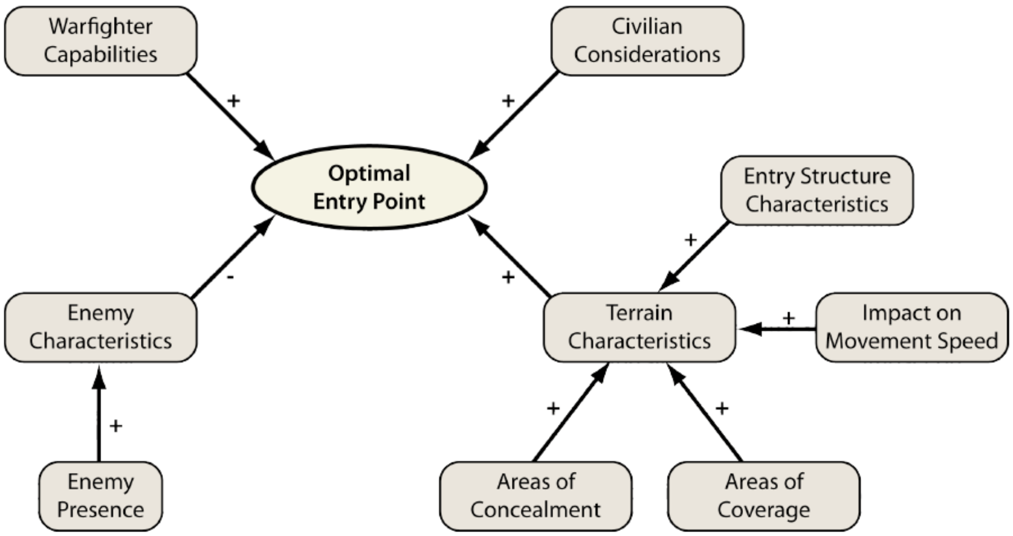


The infantry platoon leader **interprets this information** to understand if the road is traversable for covert and stealth operations. A lower dew point combined with a high humidity means that a dirt road would more than likely be wet, and therefore quieter, which is preferable for stealth operations.

<u>So the arrow begins from what causes the influence and goes towards the direction that accepts the influence</u>.

Now how those factors are **interrelated**? If the enemy presence increases, then there are more enemy characteristics to consider - these two parameters are positively connected, and we give a positive sign (+). The opposite can also happen, the increase in a parameter to decrease another one, then these two parameters are negatively connected and we give a negative sign (-).

Such an example of negative relationship in our map is enemy characteristics and how they influence the final decision for optimal entry point.



(NOTE: As a reminder to you only, do not mention it to the respondent now in the fear of providing too much information: a positive (+) relationship exists also if both factors are decreasing. Mention it to the respondent later when such an interrelationship appears. Another important point is that those interrelationships should always be examined per two, because cognitive maps assume only pairwise relations between factors).

The process of prioritizing factors parallels the cognitive processes that humans naturally employ. It is easier to characterize an event by prioritizing the conditions that must be present for an event to occur.

--- BREAK ---

7. **Now it's time to construct our own map for the overtaking procedure and I ask you: Which factors, which concepts, come into your mind spontaneously if I mention to you our use case?** Please take your time to think and write on the blank page in front of you all factors/things that come to your mind. Please write the factors for each step / event

LEAVE THE PARTICIPANT 10-15 MINUTES TO THINK

We need to determine the SA requirement with reference to the technology or to the manner the cue/information is obtained
For example, speed may be used (along with other information) to assess deviations from safe speed (Level 2 SA) and deviations from draft passage (Level 2 SA)
When the expert provides higher order information requirements (e.g., "I need to know the fairway status"), further probing will be required to find all of the lower-level information that goes into that assessment (e.g., ask "What about the fairway do you need to know to determine the status?").

During the interview listen closely for **predictions** or **projections** the person may be making when reaching a decision. Try to distinguish between what they are assessing about the current situation (e.g., 'what is the current?' – the Level 1 SA requirement "current information") and what they are projecting to make a decision, (e.g., "where will the fairway status change – the Level 3 SA requirement "projected statusofthefairway")

Distinguishing between these types of statements will assist the practitioner in following up on higher order level SA requirements and documenting lower level SA requirements.

8. Please take some post it notes and like in the platoon leader example, choose randomly two of your listed factors and write them on the post it. Now I want you to think: are those two factors directly related? If yes, draw an arrow in the direction of influence. If there is no relation, bring on the page a third factor from your list, write it on a post it and ask yourself: is this factor related to anyone of the two previous? If yes draw the arrows again showing the direction of influence.

   Remember that here we are trying to show the relationship connecting each factor with another one. For instance, if you believe that concept A influences concept B then the arrow starts from A and directs towards B. If you believe the opposite then draw it the other way. Put all other factors around, one at a time, leaving enough space for any additional information. Continue until all the factors from your list have been transferred to the schedule and all arrows have been identified. (The respondent's map is now emerging. Ask the respondents to take a look at the whole map and see if all arrows have been completed. You should check for any missing arrow).

   LEAVE THE PARTICIPANT 10 MINUTES TO THINK AND DRAW RELATIONS.

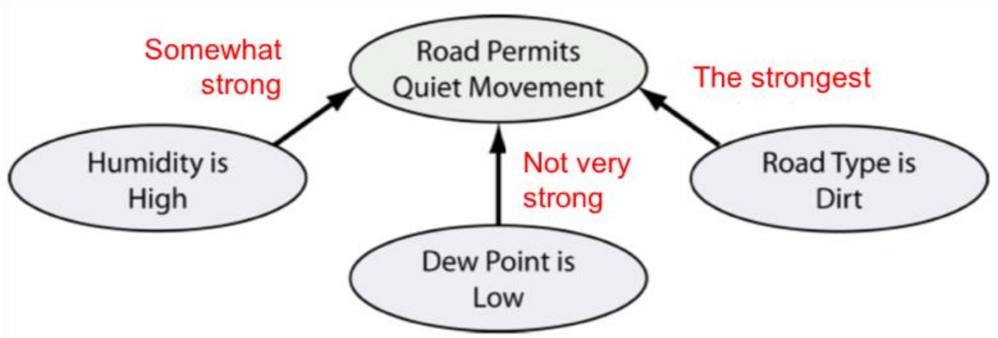
9. **Now I want to ask from you to go a bit further evaluating if the relationship between factors is positive or negative. I remind to you that in the positive relationship things are growing together or decreasing together. If one factor grows and this causes decrease to the other factor then we put a negative sign in this relationship**.
   (Repeat if needed the above example METT-TC factors). LEAVE THE RESPONDENT 5 MINUTES TO THINK AND PUT (+)/(-). If you see difficulties encourage the procedure being by their side asking them PROPER questions - NOT guiding them but ask: is there another relationship which is not yet depicted? Is A connected to B? How? Can you tell me why did you recognize a negatively strong relationship from A to B?(You might take the answer that A is interrelated to B through another intermediate parameter (factor) which was omitted by the participant due to its lower importance /or was forgotten.
10. Then tell the participant that he has to add this factor in his initial 'table' of parameters and also add it to the interrelationship map he is constructing. Start asking each time for every potential relationship that might appear in the participant's map. Do not omit any relation or otherwise the participant will think that this is not important).

REMEMBER: A good researcher is not guiding the procedure, only elicits what is hidden in respondent's mind reminding objectively each potential relationship. During this discussion you take notes of every answer that the respondent gives you. At the end of each interview you should have written all the explanations given by the participant on any personal belief/ thought behind the hand drawing the map.

11. WHEN THE PHASE OF EVALUATING ALL RELATIONSHIPS IS OVER: **Now I want you to think. How important is the influence of A over B? If you believe that the influence is <u>positive and very important we just write it</u>. Look at this scale having 5 grades capable to describe any kind of relationship between two things.**

Scale of influence

(6) The strongest
(7) Very strong
(8) Somewhat strong
(9) Not very strong
(10) Not strong at all
Alternatively: I don't know



Now using this scale, tell me what you think is the strength of relationship between the factors on your map.

For this example, the **critical factor** to stealth movement is identifying the **type of the road**. Once it is established that a road is a dirt road, the platoon leader can then consider the **dew point** and **humidity** as **factors**, and the impact of those on stealth movement. As explained by the SME, even though the dew point and humidity are related, the platoon leader is more interested in the dew point, and only cares about the humidity in extreme situations. Thus, the condition for conducting stealth movements is primarily dependent upon the road type being dirt and the dew point being low.

BE CAREFUL: Because the participants' cognitive maps are designed by hand they may be very confusing, and not readable if the numbers (strength of influence) is also added on it. Let the respondent add the numbers on the map, BUT you should clearly write on your own notes the exact number of each

Ask the respondent to tell you why he gives this number; this is a valuable info for our database.

12. **Repeat steps 9-12 for every subtask. Ask them what is changing along the progress of overtaking and why**

    This should proceed faster because SMEs are already aware of the process (15-20 min)

13. **Discuss the maps with all the participants (5-10 min)**
14. **Participants fill in consent forms and demographics (5 min)**

APPENDIX G: Consent and Demographic forms for FCM workshops participants

National Technical University of Athens
School of Mechanical Engineering
Sector of Industrial Management and Operations Research (SIMOR)
http://simor.mech.ntua.gr

Informed Consent Letter for Participation in Research “Improving Situation Awareness during safety-critical navigation activities with adaptive interfaces and information prioritization”

Dear Participant,

Thank you for your interest and your willingness to participate as a Subject Matter Expert (SME) in this workshop for my doctoral research. This informed consent letter explains the background of the study, what you have to expect and what data will be collected. You are more than welcome to contact me for questions about the study or the procedure at (pastella@mail.ntua.gr).

Background
Ship navigation is a high-risk task that involves performing complex procedures and ensuring the safe passage of vessels into and out of port through channels and restricted fairways, while making predictions about possible traffic developments. System designers aim to support the safety of navigational operations by developing ship bridge systems that communicate efficiently the available related information and respond to the cognitive demands of the mariner. The purpose of this study is to extract the cognitive demands associated with the task of overtaking and a related scenario that takes place in the Outer Weser area.

Procedure
The workshop will last 2,5-3 hours and consists of three parts. You will be introduced to the goal of the study, then proceed with the first two parts, the Task Diagram and the Simulation Interview. These parts will involve questions/probes targeted at decision making activities during a task implementation and a walkthrough of the task with the support of a map. Then, I will briefly explain the Cognitive Mapping methodology of the third part. After a short break, we will proceed with the modeling workshop, where you will build a cognitive map.

During our discussion, you are strongly encouraged to express freely your opinion and your view on the matter- there are no wrong or right answers, there are simply different opinions. A shorter follow-up interview may be needed for added clarification or to gather some more data. If so, I will contact you by mail/phone to request this.

Data Collection
I will collect some demographic data of you in a document and with your permission, I will audiotape, video record and take notes during the interview. The recording is to enable a better flow in the study, to accurately capture the information you provide, and **will be used for transcription purposes only**. No videos or photographs of the participants will be published or shared. If you choose not to be audiotaped or video recorded, I will take notes instead, but this might result in a longer interview.

Confidentiality

Your study data will be handled as confidentially as possible. If results of this study are published or presented, individual names and other personally identifiable information will not be used.
To minimize the risks to confidentiality, study records will be accessible only to the researcher involved in this study and the thesis committee. The audio and video files will be encrypted and stored in a safe location. When the research is completed, I may save the notes for use in future research done by myself or others. I will retain these records for up to 10 years after the study is over.

Rights

Participation in research is completely voluntary. You are free to decline to take part in the project. You can decline to answer any questions and are free to stop taking part in the project at any time. At any time without giving reasons, you can revoke your consent for the usage of the collected data.

Questions

If you have any questions about this research, your rights or treatment as a research participant in this study, please feel free to contact me. I can be reached at pastella@mail.ntua.gr - Tel. (+30) 6973 497950
You can also contact the supervisor of my thesis, Assistant Professor Dr Dimitris Nathanael Tel. (+30) 210 772-3938, email: dnathan@central.ntua.gr

Thank you for your participation
Stella Parisi

CONSENT

You will be given a copy of this consent form to keep for your own records. If you wish to participate in this study, please sign and fill in the date below.

My participation can be audiotaped/recorded.

I allow the handling of my data from the researcher and the thesis committee.

Place, date & signature of the participant: ________________________

Name of the participant in CAPITALS: ________________________

Place, date & signature of the researcher: ________________________

Name of the researcher in CAPITALS: ________________________

National Technical University of Athens
School of Mechanical Engineering
Sector of Industrial Management and Operations Research (SIMOR)
http://simor.mech.ntua.gr

Participant’s Demographic Data

Interviewee Details

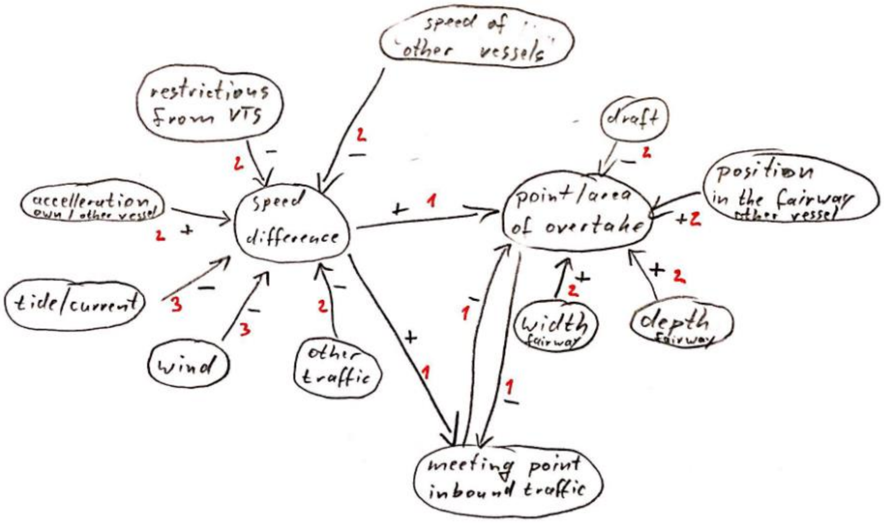
Name:
Title: Age:
Location: Date: Time:
Email:
Telephone:

Expertise Information

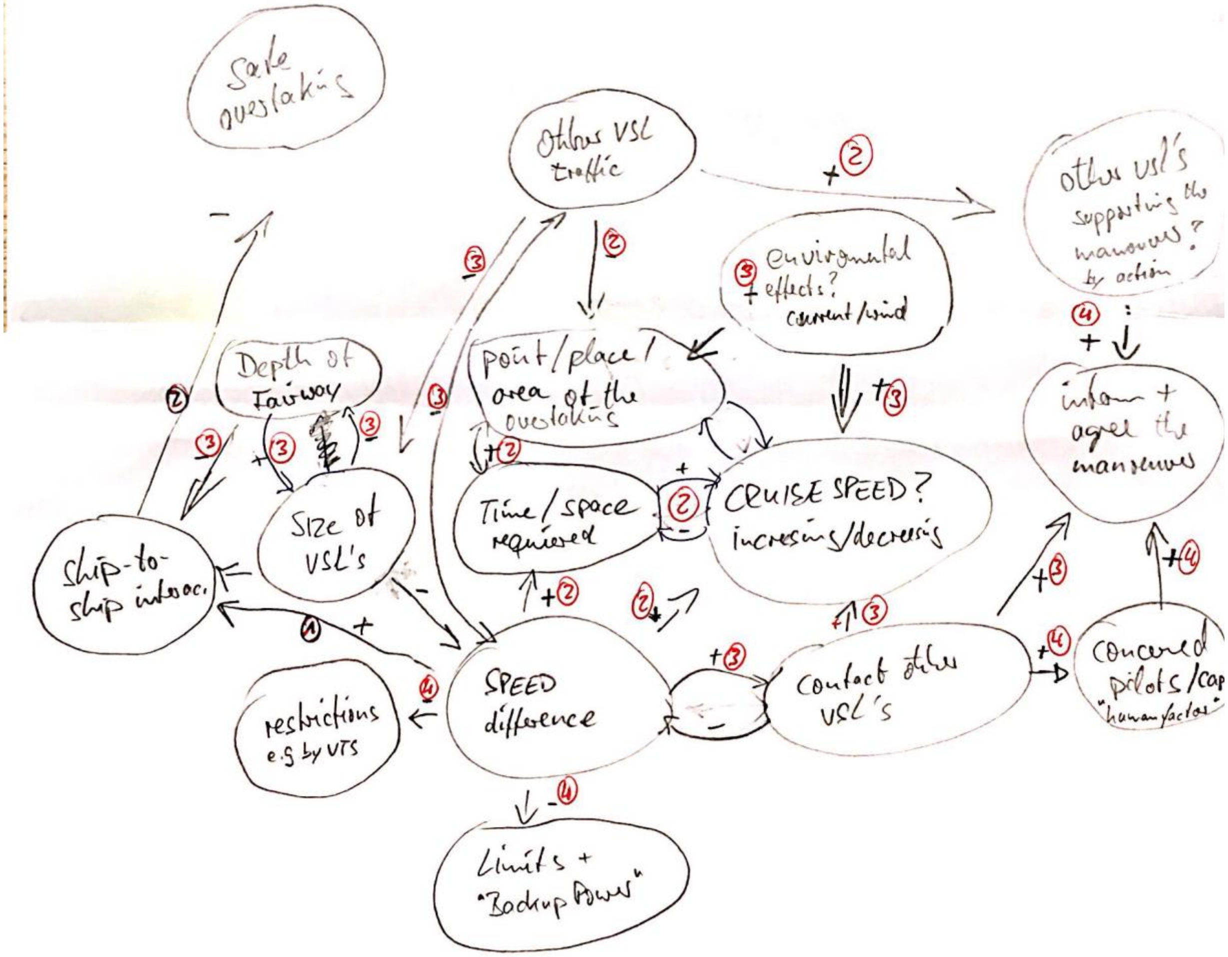
Years Active:
As master mariner:
As pilot:

Additional Notes

APPENDIX H: PARTICIPANTS' MAPS FROM FCM WORKSHOPS



- speed of own vessel (actual and max.)
- how fast can own vessel accellerate
- speed of vessel ahead actual / is speed increasing?
- speed of inbound vessel / will she slow down?
- tide / currents
- wind
- draft of own vessel and of the other vessels
- where is the point / area of overtake
  ↳ width / depth
- restrictions from VTS
- can communication be established with the other vessels if necessary / how do they respond
- visibility
- other traffic inbound / outbound



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①
- SPEED diff.
  to overtaking vsl
- Calc. point/area
  for the manoeuvre
- OTHER vsl traffic
  affecting the manoeuvre
  (inbound + same direction)
- restrictions of e.g. speed
  by VTS
- Limits
- "Backup Power"?
- SIZE of the concerned vsl's
- ship-to-ship interaction

②
- current condition
- weather condition
  here: wind force/direct.
  visibility
- Fairway area/space
  required for the manoeuvre
- depth of the Fairway in
  concerned area
- draught of the concerned
  vsl's
  - ↳ to have an idea what
    might happen concerning
    the hydrodynamic effects

③
- experience of/with
  concerned pilots
  "human factor"

④
- inform/agree the manoeuvre
  with concerned vsl's
- ask for support of the
  planned manoeuvre
  - ↳ speed increase/decrease
    of vsl's
  - ↳ Position in the Fairway

⑤
- check + double check
  the started/calculated
  manoeuvre
- "abort point"
- "Plan B"

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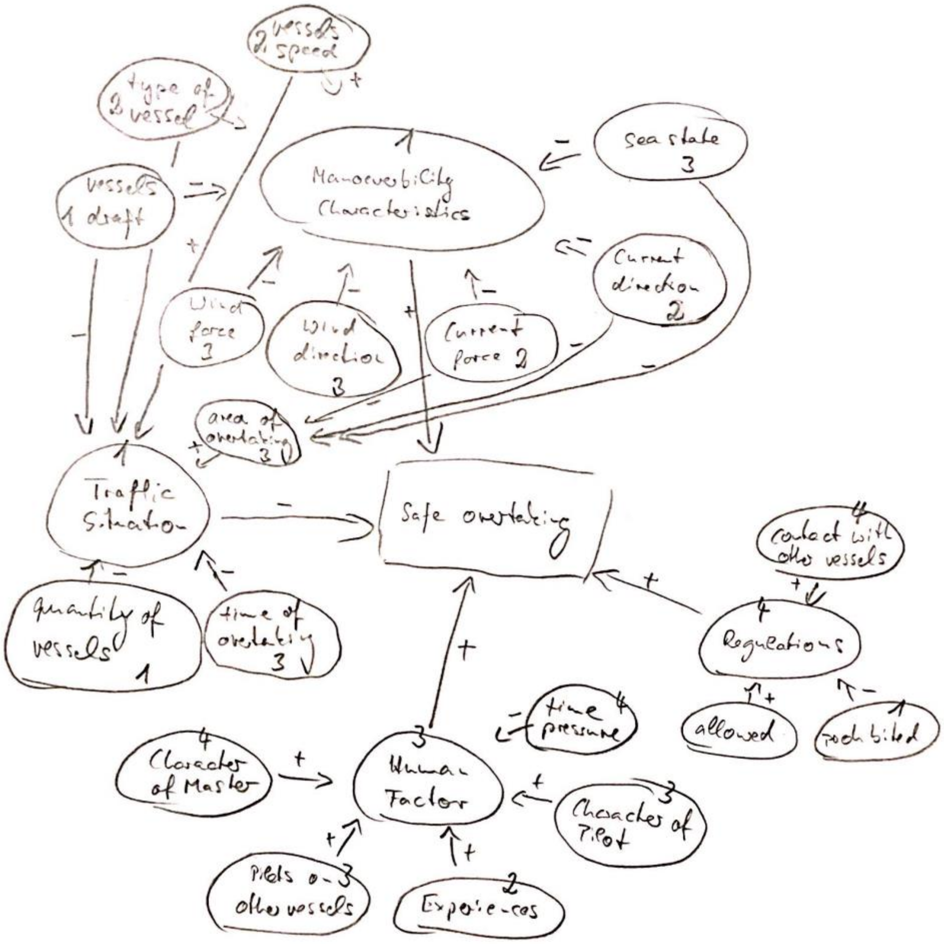
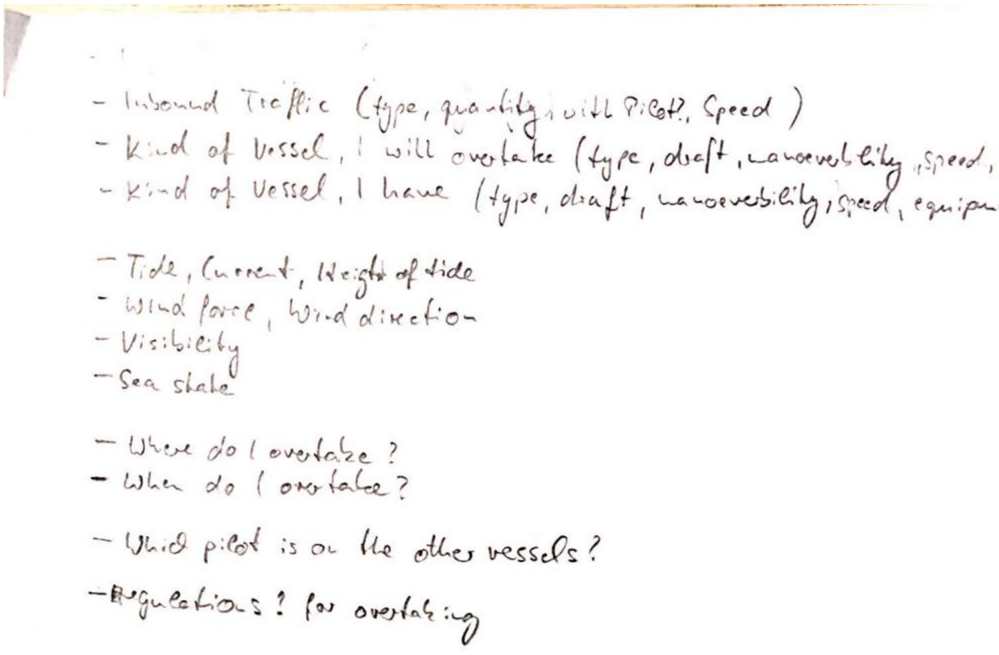




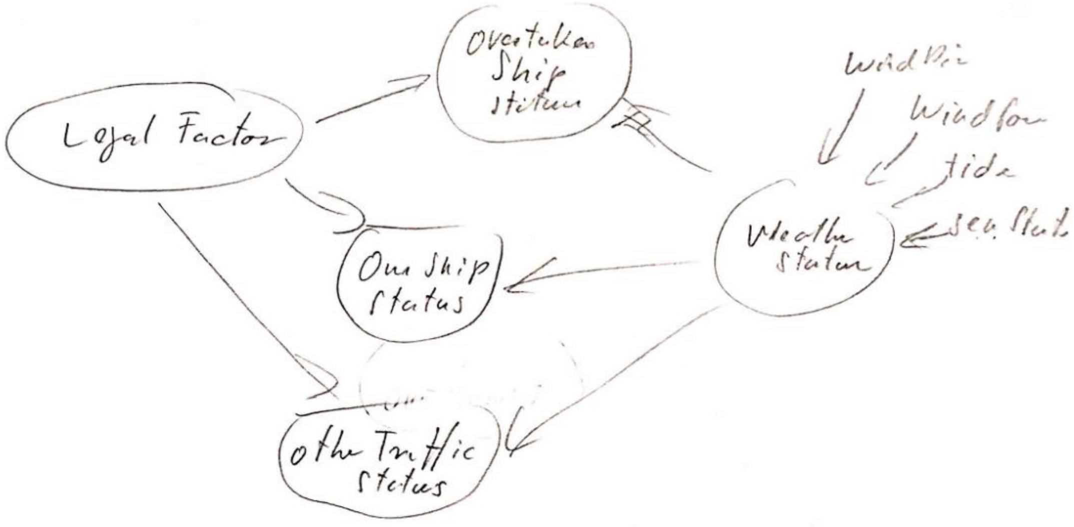
- Inbound Traffic (type, quantity, with Pilot?, Speed)
- Kind of Vessel, I will overtake (type, draft, manoevebility, speed, with Pilot?)
- Kind of Vessel, I have (type, draft, manoevebility, speed, equipment)

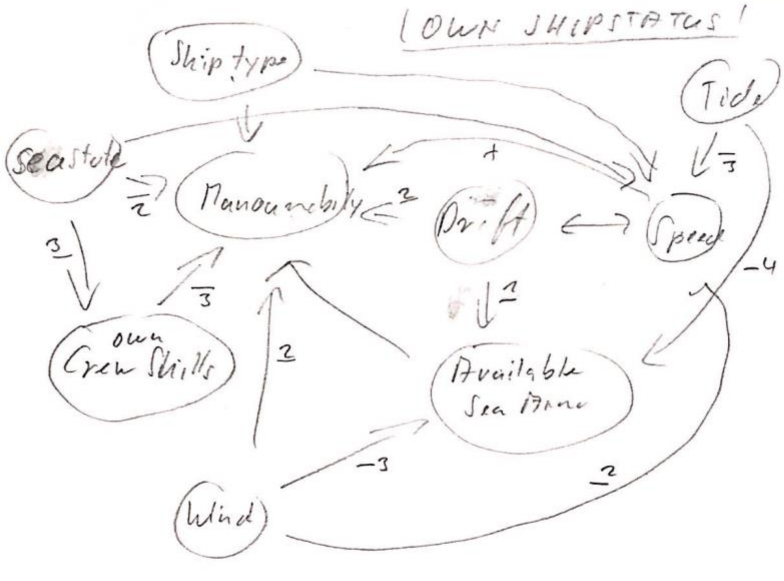
- Tide, Current, Height of tide
- Wind force, Wind direction
- Visibility
- Sea state

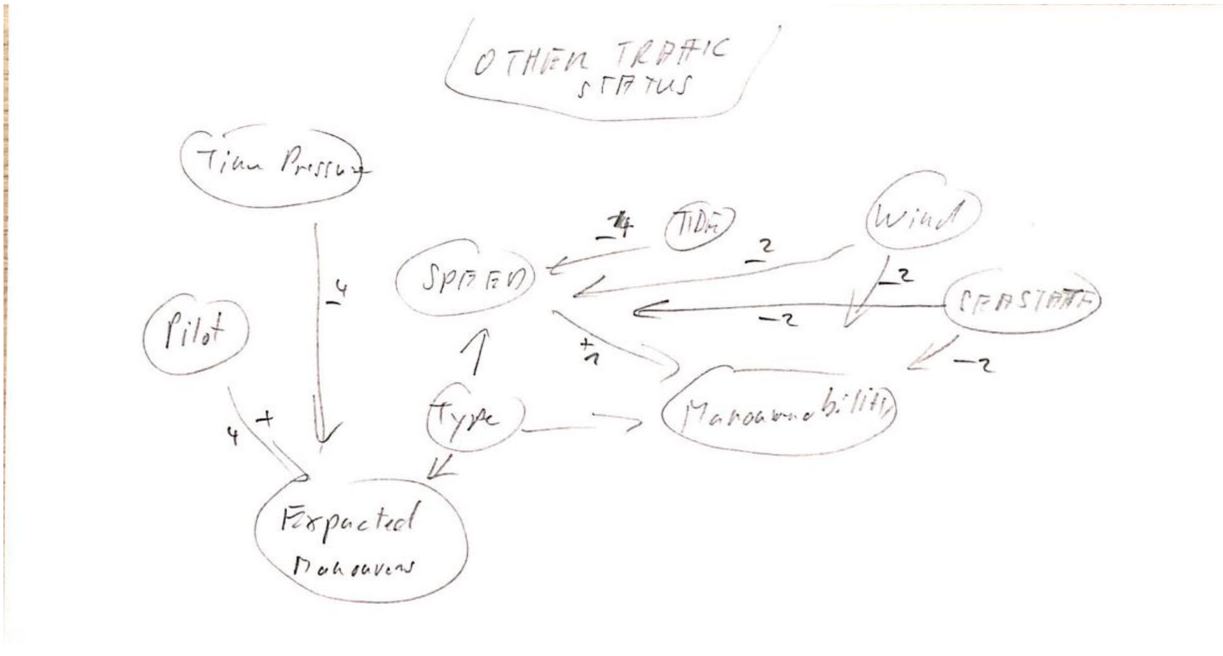
- Where do I overtake ?
- When do I overtake ?

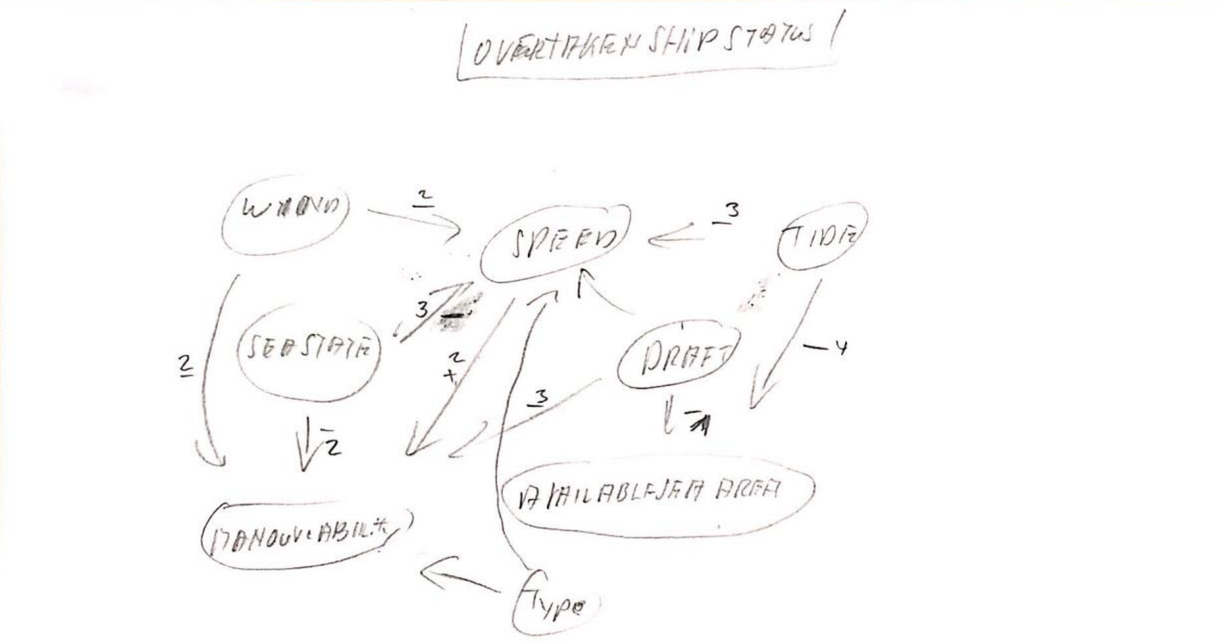
- Which pilot is on the other vessels?

- Regulations ? for overtaking


Overtaken Ship status
Legal Factor
Wind Dir
Wind force
tide
sea State
Weather Status
Own Ship Status
other Traffic Status


OWN SHIPSTATUS
Ship type
Tide
seastate
Manouverbility
Drift
Speed
+
2
2
3
3
3
1
-4
own Crew Skills
2
Available Sea Area
Wind
-3
-2


OTHER TRAFIC STATUS
Time Pressure
Pilot
SPEED
TIDE
Wind
SEASTATE
Type
Manoeuvrability
Expected Manouvers
-4
-2
-2
-2
-2
-4
4
+
+1


OVERTAKEN SHIP STATUS
WIND
SPEED
TIDE
SEASTATE
DRAFT
AVAILABLE SEA AREA
MANOUVEABILITY
Type
-2
-3
3-
+2
2
-2
-3
-1
-4

Weather
- Visibility
  - Day/Night
  - Rain/Fog/Snow
- tide
  - Direction
  - Heights
- Wind
  - Dir
  - Force
- Sea (Swell- Heights

Own Ship
- Speed
- Draft
- Type
- Manouevrability
- Crew Skills
- Legal Restrictions (VTS)
- Time Pressure
- Orders to be at a certain Position at a certain time

Ship to overtake
- Speed / Difference
- Draft
- Type → Manouevrability
- Pilot yes/No
- Legal Restrictions
- Time Pressure
- Orders to be . . . .
- Reaction of Captain/Pilot on Information to be overtaken.

Sea Area
- Depth
- Current
- Water area available

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APPENDIX I: FCM VALIDATION WORKSHOP WALKTHROUGH

1. Introduction

2. We know 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.

3. EXPLAIN THE COLOURS: I will now show you my screen and see the FCM that we have created. Before we begin You may have noticed that some concepts are coloured. For example, all the concepts that are pink are related to Human Factors aspects. Green stands for environmental concepts, Blue stands for concepts related to the Vessel to be overtaken, Orange stands for concepts for own vessel, yellow stands for concepts for other vessels and the rest are white

Show the Lines from/ Lines to feature with Current

4. First let's start with your opinion on what are the most important concepts to you that can trigger safety in an overtaking maneuver.
>Θα ξεκινούσα με τους drivers. Παρόλα αυτά, στην κουβέντα με τους experts , θα ρωτούσα ποια concepts είναι για αυτούς σημαντικά ώστε να ξεκινήσει το triggering.

Questions

1. Is there an effect of Effective Area of overtaking on SAFE OVERTAKING? In the current map, the Effective Area of overtaking affects the COMPLEXITY OF TRAFFIC SITUATION and then SAFE OVERTAKING
2. Does sea state (wave & swell height) affect Human Performance?
3. what about radio assistance from shore pilot? it was apparent from previous interviews that it helps. We don't have a concept like this here.
4. What about the effect of Manoevrability of other vessels to the Complexity of Traffic situation?
5. Your colleagues had mentioned the vessel type as factor BUT we replaced it with draft and size. The reason we replaced it is because we need to have a value in each concept and type of ship could not function in the model πρεπει να εξηγήσουμε οτι καναμε αυτη την αλλαγή για λογους του μοντελου
    a. what will happen with the ship type which is included in the maps and plays a crucial role for the manoeuvrability concept
    b. Will we do it according to our scenario? How can it be generalized?
    c. Is there another aspect of vessel type that should be included in the model?

6. Complexity of Traffic situation < - > Effective Area of overtaking (-0.25 effect, both ways
7. Size of vessel(s) > Complexity of Traffic situation

   Which one affects the other? Is there a relationship here?

   How does size of vessel work with complexity of traffic situation
8. Can you explain the differences in the effect? Is it because of the ship type?

   wind effect > Manoeuvrability OWN vessel = -0,625

   Manoeuvrability VtO = -0,625

   Manoeuvrability other vessels = -0,75 (In our example, OTTAWA)

Scale of influence

1. The strongest = 100% or 1
2. Very strong = 75% or 0,75
3. Somewhat strong = 50% or 0,5
4. Not very strong = 25% or 0,25
5. Not strong at all = 0
